An Investigation in the Use of Combat Effectiveness
as a Method of Selection
of Naval Vessel Characteristics

by

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ABSTRACT

This project develops a framework to permit the introduction of combat effectiveness as a high level objective function to the naval ship design process. This is effected by the development of a model of the sources of mission requirements for the design. Interaction and inter-connection of the design stages is provided by designing the model around the menu-oriented software system known as DEX (Decision Executive System).

The model used the commonality of its' design and the DEX commands and prompts as the means of insuring that all participants to the design process have access to the assumptions used to develop combat effectiveness as an objective function. The possible capabilities of the model are exhibited through simple examples which show the extreme situation dependency of combat effectiveness assessments. The possible implications of the use of the model for future research in Naval Architecture/ Marine Engineering are discussed.

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THIS PROJECT WAS ONLY POSSIBLE BECAUSE OF THE UNSELFISH SHARING OF A NUMBER OF PERSONS OF THEIR CONSIDERABLE TALENTS AND KNOWLEDGE. IT IS SINCERELY HOPED THAT EACH OF THEM FULLY APPRECIATE THAT EACH OF THEM WAS ABSOLUTELY NECESSARY TO THE FINISHED PRODUCT.

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And my lasting thanks to my inspiration and motivation -
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CHAPTER 1

INTRODUCTION TO THE PROBLEM

The objective of this work was to establish a set of independent variables to describe a mono-hull surface combatant ship (naval vessel) and to determine its mission effectiveness. This determination will be made at the feasibility stage of the design and will be dependent upon the environment in which the design is to operate. It was determined that all variables would be specified by their contribution to specific missions. It was expected that the determination of these contributions would eventually permit an evaluation of the designs' combat effectiveness. As in any large scale system definition, the question of appropriate level of detail was critical. This project will attempt to specify these independent variables, both in number and in detail, sufficiently to permit determination of:

1. feasibility under known or assumed technological and budgetary constraints
2. combat effectiveness
3. non-combat mission effectiveness
4. cost effectiveness.

Progress in the development of this set of independent variables was, initially, very uneven. The first problem was to establish a complete listing of all missions for such a ship. It was determinted that the best existing list of this sort would be a good point of departure for this problem. Research toward finding such a document eventually lead to a publication entitled Naval Warfare Mission Areas and Required Operational Capability, also known as OPNAV Inst. 3501.2E. This instruction is used to indicate which mission areas, of all possible U. S. Navy missions, have been assigned to a particular class of vessels. It also lists the assigned missions by the portion of the ships' organization (operations, engineering,etc.) which the mission is assumed to affect. As such, this instruction is an excellent attempt to describe all missions which a particular ship is "expected" to be able to perform when properly (fully) manned and when all installed equipment is fully operational.

The possible missions listed in OPNAV Inst. 3501.2E could be broadly separated into two categories; combatant and non-combatant. Within this instruction, the descriptions of the two types of missions are quite different. A typical noncombat mission entry might be described as "Search and Rescue", with the the equipment and training levels for the

ship and crew being specified. Conversely, A typical combat mission entry might be "Force and Area Air Defense", and would generally be without any further explanation.

This "underspecification" of many missions within this publication is most clearly shown in the listing of many general combat missions. In our previous examples of Force and Area Air Defense, the problem with the statement of the mission is that it is, in addition to being somewhat subjective, very "relative". It is most relative to the forces which might be attempting to defeat the proposed defense. It is also dependent, among other things, upon which other ships are in company. In short, the whole mission area can only be defined in terms of a broad spectrum of possible situations.

Since the non-combat mission area assignments in OPNAV Inst. 3501.2E were considered satisfactorily specified, this publication was chosen as the basis for the selection of hardware resources necessary to perform those types of missions. The combat mission areas, however, were not defined well enough within that instruction to be used to determine the direct effect of the missions upon the ship and its' systems. Therefore, it was necessary to establish a methodology within the model which would permit sufficent

description of combat type missions. This framework was intended to provide that definition by allowing the mission to be described in terms of the operational environment within which the ship would be designed. This environment will include the contributions or detriments to combat effectiveness created by man-made and natural situations which the design might encounter in combat. Later, it was found that this "threat and environment" model would form the foundation for the evaluation of combat effectiveness of a ship. It must be kept in mind that both the platform and the payload were being, thusfar, described only in terms of what they must do. We were carefully avoiding any attempt to define the missions in terms of the means to be used to accomplish them.

Now, we may address the various independent variables defining our theoritical ship in terms of the requirement but more importantly in terms of the source of the requirement. The other two major sources of naval ship mission requirements were assumed to be; 1. Non-combat mission requirements - it was assumed that the requirements of OPNAV Inst 3501.1E satisfactorily listed these. 2. Estimated time/cost requirements; which might be considered a form of filter to the first level feasibility of the conceived payload. If all possible sources of the defining parameters

can be identified then we may be assured of addressing requirements in the construction of our model. To this point we have identified the types of vessel requirements as follows;

REQUIREMENT	SOURCE
--Combat Payload	--Opponent, Environment, Forc in company
+	
--Non-Combat Payload	--U. S. Navy (through society
Equals "PAYLOAD"	

In the same vein;

REQUIREMENT	SOURCE
--Payload	--as above for payload
+	
--Platform Parameters	--Naval Architect as per guidance provided by others
Equals "SHIP"	

The assumption made to this point is that, if the requirements of the different "sources" of ship characteristics could be clearly and completely defined, we could

translate these requirements into hardware; that is a ship. Even if we were entirely successful in this difficult translation, we would be left with two important questions. 1. How "good" was the ship we had created? 2. What technique(s) could we use to permit timely processing and data manipulation of the numerous items which must be included in even the simplest of ships?

The answer to the question of assessment of the "quality" of the designed ship depends in large measure, upon the assessors' definition of "goodness". In other words, it might well change with a change in assessor. With this in mind, the next logical step in the development of our model would be a tabulation of all significant measures of surface combatant vessel "performance".

Previous ship synthesis models (we will roughly define SSMs as computer aided interconnection of the various ship design sub-stages) have focused upon the "non-combat" type performance measures. Toward the assessment of such items as cargo carrying capacity, rates and costs and even total "life cycle" costs, these models have made significant progress. In our case, we have, with the development of the combat situation framework, provided, in theory, the

information necessary to conduct a measurement of combat performance within the design process.

Model Outline

We can now look at the "flow chart" describing our approach to designing a Mono-hull surface combatant and the assessment of that design. See figure 1.

As will be recalled, the general approach was to , first account for the different independent variables "driving" the design, by source. Referring to figure 1 these were;

The environment in which it would perform the "combat" missions (1a)

The "non-combat" missions to be performed (1b)

The material and financial resource considerations of both missions (1c)

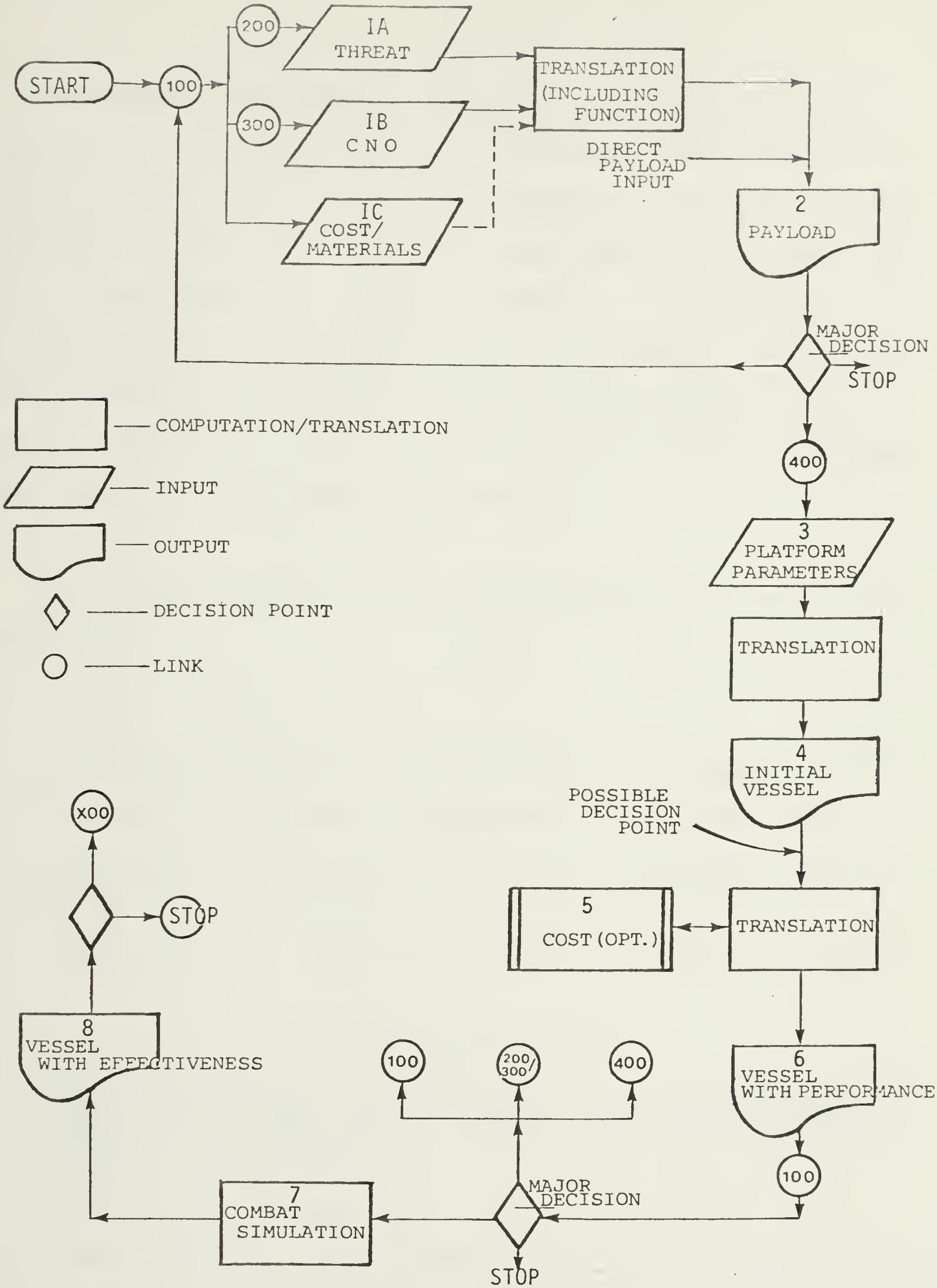

START
100
200
IA
THREAT
300
IB
CNO
IC
COST/
MATERIALS
TRANSLATION
(INCLUDING
FUNCTION)
DIRECT
PAYLOAD
INPUT
2
PAYLOAD
MAJOR
DECISION
STOP
COMPUTATION/TRANSLATION
INPUT
OUTPUT
DECISION POINT
LINK
400
3
PLATFORM
PARAMETERS
TRANSLATION
4
INITIAL
VESSEL
POSSIBLE
DECISION
POINT
5
COST (OPT.)
TRANSLATION
X00
STOP
8
VESSEL
WITH EFFECTIVENESS
100
200/300
400
6
VESSEL
WITH PERFORMANCE
100
7
COMBAT
SIMULATION
MAJOR
DECISION
STOP

FIGURE 1

The simple identification of these requirements is a necessary but not sufficient step in the total design of a vessel. We must, then identify the "blend" or "mixture" of the hardware items created by those requirements into a measure of "goodness" or more correctly a "measure of effectiveness". More precisely, we will look at the problem as a determination of the resultant effectiveness of a specific combination of the variables.This determination was made using utility theory (see chapter 5)

The major synthesis steps, as provided for in this model would be;

Translation of mission requirements into a payload (T1)

Translation of platform parameters into a "ship" (T2)

Estimation of the ship in terms of non-combat performance (E1)

Estimation of the ship in terms of combat performance (E2)

Model Design Philosophy

Before describing the model in detail, we will discuss the "design philosophy" of the model. The following characteristics were determined to be the most important in the development of the model.

1. "Performance" Based

2. Computer based with the DEX software (see chapter 2)

3. Highest level development

Performance Based

Most existing ships synthesis models might be best described as the "one shot" method, where the objective becomes the satisfaction of a set of given requirements. These are usually the ability to carry a certain amount of equipment, or perhaps, some type of vessel charactertics such as geometry and powering. The problem with this type of approach is that the input is considered invioliate and the user can not regard any violation of assumptions made at an earlier stage of the design which lead to these conclusions. An associated problem with this approach is that to reach such a state of specification the user most likely conducted much preliminary work prior to exercising the model. In short, much of the most involved design work has been conducted external to the possible assistance of the computational and data storage/retrevial abilities of the computer. A third problem common to most existing models is the virtual lack of interaction. The essentially batch or "one-shot" method used in most adequately-supported models requires the entire process to be repeated to discover the effect of any changes.

As bothersome as the perviously described shortcomings to existing SSMs might be, the lack of adequate effectiveness

measurement is far more serious. Most common measurements are implicit co-relationships of displacement, fuel or manning levels to cost. Such variables are,indeed, important to the peace time portion of the life of the vessel. They do not, however, address the true reason for existance of the combatant, that is its performance in combat, itself. Historically such an assessment has , at best, been conducted totally separate from any non-combat performance evaluation. In the most common practice, any combat system design performance evaluation is conducted on a single system by system basis without any integration of the system resource requirements upon the vessel design. For example, the performance evaluation and resource requirement identification for an anti-air missle system would not address any impact of those resources upon the performance of, say the anti-submarine weapons suite. In truth, the earliest time a total design is subjected to a combat performance analysis is usually after initial fleet introduction of the design. At this point the ship is "synthsized" according to its "major" characteristics and modeled by interested activities. These models are then "gamed" against similarly conceptualizsed opponets. Two important points should be noted. First, this process is done after we have paid full price for the vessel without the opportunity to correct any discovered weaknesses prior to completion. Second, the

information of how the "modelers" "fought" the ship is not retained.

It will be the implicit assumption of this effort that the proper assessment of a combatant ship design should include an internal estimation of "combat effectiveness".

DEX as the computer software package

Given the necessity for computer aid in the modeling of the complex ship design process, the choice of operating software becomes critical. The major characteristics of the DEX (Design Executive) system, chosen for this model, are included in chapter 2. Also included in that chapter are the effects of those DEX characteristics upon the capabilities of the model.

Highest Level Development

In the development of any model, the selection of the characteristics which will be used to describe the modeled entity is critical. The challenge is to include all necessary characteristics and no unnecessary ones. In the development of this model, an attempt has been made to identify all those variables needed to formulate the problem at the fea-

sibility level. It is intended that the model provide for the inclusion of all variables which could, at this feasibility level, affect the evaluation of the designs' combat effectiveness.

CHAPTER TWO

The Design Executive System (DEX)

The methodology for this model was designed to be installed within the Design Executive System (DEX) under development at Massachusetts Institute of Technology and the University of Mighigan. DEX is a self-contained software package which is adaptable to almost any computer system supporting fortran. It provides a system for running task based programs, called "modules". Primarily, DEX supports interactive programs and it provides this interaction by communication between five "parties". These parties are;

1. The user
2. The computer
3. The computation program
4. The source of the input
5. The destination of the output

The degree of active involvement with DEX is within the prerogative of the person writing the particular application program. That is the "module author" may choose which DEX services to use

There are five major characteristics of DEX:

1. The user is in the design loop.

2. DEX allows the design process to be executed in more than one sequence.

3. DEX "talks" to the user in plain english.

4. DEX is "forgiving".

5. DEX has multiple capabilities for input and output.

1. The user is in the design loop. The ship design spiral vividly demonstrates the strongly iterative nature of the ship design process. The ability to perform data manipulations to a specific point and, then, analyze those results to decide where or if to proceed is vastly preferrable to a "through-put"operation. DEX enables the user to choose a new path, obtain new information or to edit and insert information before it is used within computation sections.

2. DEX allows the design process to be executed in more than one sequence. This is accomplished by providing the user with a scheme for generating menus within his application program. The use of "menus" to provide the user with a range of choices of possible decision paths toward his goal. A menu is a list of options (with a current maximum of 12 per menu) from which the user chooses to either define a data value or proceed to the next step of the operation.

An example of a menu is included in figure 2. If the user desired to specify or identify a type of weapon from this menu, he would type in sufficient characters to uniquely identify that weapon within that menu. Examples might be "t" for torpedo or "aa.m" for AA.msl. The subprogram would accept this choice, if valid, and execute the segment of the program that is logically associated with the menu choice.

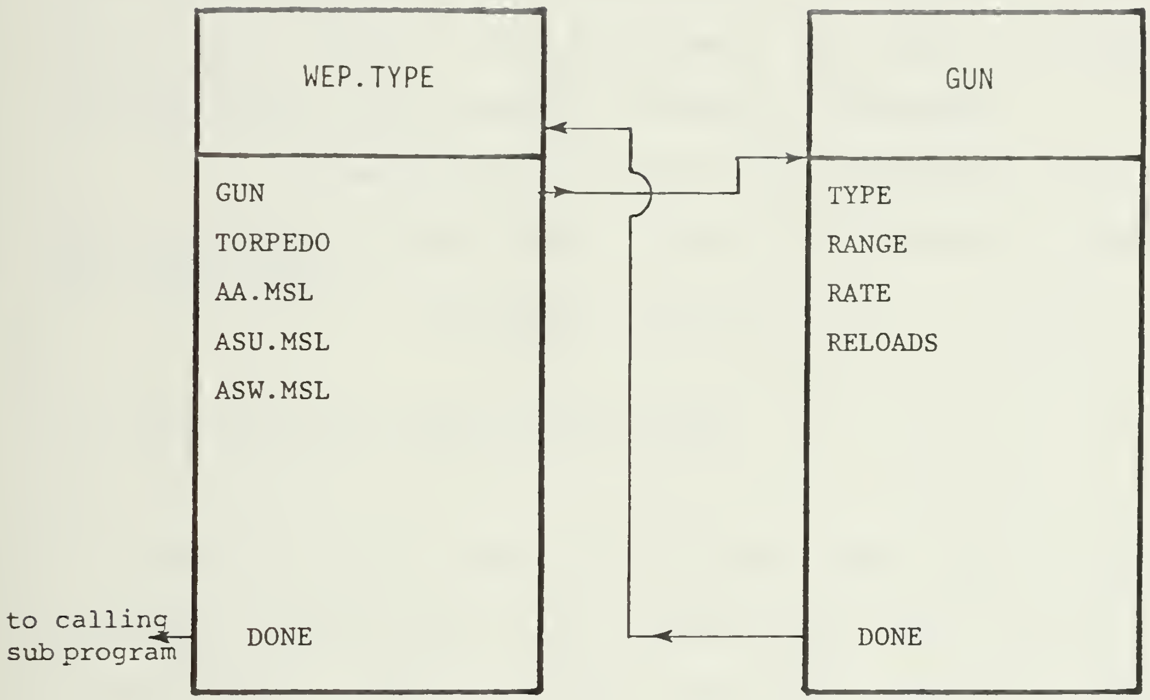

WEP.TYPE
GUN
TORPEDO
AA.MSL
ASU.MSL
ASW.MSL
to calling
sub program
DONE
GUN
TYPE
RANGE
RATE
RELOADS
DONE

FIGURE 2

If the entry is not valid, the user will be prompted, again, for an entry from the same menu. It is not necessary that the menu, itself, be displayed. If the user is familiar with the choices within the menu, he might be prompted to make a choice, from memory, by seeing displayed

*enter an item from menu-wep.type

If however, the user does not know the choices of this menu he could type

$ display menu-wep.type

to have the menu displayed by DEX.

Note the use of "done" as the last menu item in figure 2. A sub program with a menu containing "done" returns to the sub program which called it only when "done" is selected. Without "done" the control of the program is automatically returned. Such a menu, therefore, can only have one choice made at a time. The user is free to choose menu item(s) as desired. This means there is no predetermined path through a group of related of "stringed" menus, the user specifies the path.

3. DEX talks to the user in plain english. The menus, messages and questions to the user generated by DEX have been specifically designed to be as easily understood as possible. The instructions which the user must supply are intended to be as nearly "conversational" in nature as they could. All dialoge encountered by the user has also been standardized within the DEX modules as much as possible to reduce learning effort when using a new program.

4. DEX is forgiving. Because of the extended "pathing" of DEX, there is considerably more "mental discipline" required in its' use. Because of this additional "thinking" the possibility of error is also increased. These errors might range from inadvertently depressed keys, to errors in desired process. When existing sections of DEX and its library routines were developed, as many potential errors and corresponding diagnostic messages as possible were anticipated and included. When an error is detected control is always returned to the user for resolution of the error without interrrupting the execution of DEX or the module.

5. Multiple input-output capability. DEX is designed to permit communication between;

1. Data Bases
2. Disk Files
3. Terminal screen for alphanumeric characters or graphics

In general, the DEX operating environment may be described as having a total of five "sources" of information and four information "destinations". The term "information" is used in preference to input or output to reflect the duality and inter-changability of these two processes. For this reason, the author will apply the term "information" to variables which might be input or output, as values having source or destination.

The sources and destinations for information provided within the DEX operating environment are:

1. DEX-created data bases
2. The user via terminals using DEX routines to read or write alphanumerics
3. The user via terminals or plotters using graphics to read or create x-y co-ordinate plots
4. Sequential files
5. Module default (source only)

The user may use a different type of destination, as his source may use different sources for information. For example, the user might read information from multiple data bases and write the information to another terminal or a file or both. The only restriction is an essential out-growth of logic; a module can be directed toward only one source or destination at a time.

As may be obvious, DEX offers considerable improvement in facilitation of interactive design process management. It is designed to be consistent and flexible, providing "room" for the required magnitude and differing forms of information, processes and paths required in modern ship design.

An explanation of DEX sufficient to develop the reader into a proficient DEX user will not be included in this paper. An excellent reference toward that end, however, is An Investigation into the Use of Data Bases in Computer-Aided Design, by LT Richard Celotto, USN 1981. It will be necessary to describe the major terms used in the system to permit easy reference.

DEX consists of three levels of programs:

1. DEX proper- These several hundred subroutines provide the operating "umbrella" of DEX. These subroutines are designed to provide a uniform appearance of the system

to the user of the various modules. In general, they provide consistent input-output and data manupulation capabilities throughout the system.

2. Extented DEX library- this is a collection of 45 subroutines and general functions designed to facilitate the construction of a module with a program specific purpose. These include; reading, writing, editing, unit conversion, and messages and status indications.

3. Module- A module is a complete set of subprograms written and executed together to perform a specific task. It may only have one program or it may have many additional subprograms employing menus to take full advantage of DEX and any extended library functions desired.

One concept of DEX is critical. DEX identifies a variable within a data base by its name and not by its location. To use this capability, the data base must be properly constructed by the use of the command in the DEX proper main menu "DBEDCMDS" or the data base management routines listed in Celoto pg 30. Once these format rules have been observed, arrangement of variables within the data base may be made without regard to sequence. Thus, for example, if a user needed the value in a data base corresponding to a ships length, he might retrieve that value at address "length". He would not have to specify (or know) that the desired value is in the fourth or tenth entry in the data base. This is a powerful and new approach and it permits a user unfamiliar with a specific data base to obtain included information with much less prompting instruction.

Another very important feature, a feature absolutely critical to an interactive process, is that it can be edited from within DEX but outside a user module. This capability allows the user to over-ride, if he desires, a program created result and input, directly, an alternative.

CHAPTER 3

Section Development Example

This chapter will outline the techniques used to develop the sections outlined in chapter 1. The section chosen for this explanation is "Threat and Environment".

The initial work within each section was to research the general topic; in this case the natural operating environment and the possible combat threats which our design might encounter in the performance of its assigned missions. In the beginning of the effort it was important to be alert to any and all information on the subject. Thus, the earliest work was directed to put the widest possible bounds about the area. In this early stage, the best source of these bounds was conversations with leading academic and professional experts in the field. Other early sources included professional journals, proceedings of applicable societies and unclassified professional development publications for United States Naval officer warfare specialty qualfication. In this section, We began with the three classic threats; air, surface, and sub-surface. Literature alerted us to the necessity to include land based targets as a potential "threat". Later, conversations with "experts", especially "wargaming" types, proved that certain aspects of weather,

general jamming environment and the use of decoys were all matters which could have major impacts upon threat development. Through an involved iterative process the following seven areas of "environment and Threats" were proposed and accepted as inclusive.

1. SURFACE- surface ship and mine threats
2. SUBSURFACE- submarines, swimmers and submerged mines
3. AIR- aircraft or missiles
4. LAND- missile sites or cities
5. JAMMING
6. DECOYS
7. WEATHER- environment including temperature, seas, visability

At this point, the first order parameters of the "Threat and Environment" had been identified. Attention was then directed toward specification of the independent variables defining each of these seven areas; the sub-elements, if you will. The process described for the determination of the threat environment was repeated, in scale, for the identification of the factors constituting each of them.

The investigative method used in the detailed development of each section investigated in this report was:

1. An initial estimate of the elements was made.

2. A literature review of both classified and un-classified sources was conducted to provide a first refinement of the initial list.

3. Private enterprise and military experts were consulted tofurther refine the list.

4. The initial framework of the section was established.

5. The team worked with the thesis advisor and contempories to confirm that the included elements had proved major impact upon the next higher level definition of our design. This work also ensured that the arrangement of the variables could be efficently implemented within the DEX framework.

A discussion of what was, and perhaps just as importantly, what was not, included in this example section should be provided to demonstrate the process. In the case of overall combat situation definition, it was considered essential to include the elements which aided the ship, as well as the "threat". Therefore, this section would have to permit the presence and effect of friendly or aiding ships, aircraft or any other such elements as positive contributions to the operating situation. It was decided to assume that, in the absence of information to the contrary, each side (them or us) had any capability known to be possessed by either. This is a conservative assumption but is important for several reasons:

development of either side as a complete model, automatically models the opposition.

most operational commanders will make such an assumption in the employment and operation of their ships.

In the case of our example section the next step after identification of the seven major areas was the identification of the subelements to each area. In the case of "air threats", the author's initial estimate of the appropriate subelements to "air threats" was:

1. SPEED
2. ALTITUDE
3. NUMBER
4. SIZE
5. DECOYS

From several visits to the U.S. Naval War College and from discussions with personnel in Washington, D.C. concerned with weapons system development and intergration, this list was modified as follows "speed" became two speeds; inflight speed - the normal "cruising" speed of the threat, and "terminal" or final speed of the threat as it made a final approach to the target (in this case us!). Although some weapons entire flight was conducted at a single speed, it is much more common for the majority of distance from launch to target to be conducted at the relatively low speed

to ensure a maximum range. Typically, the threat will then conduct a radical altitude change manuver such as a "pop up" from a low altitude approach or a "dive" from a high altitude approach to effect a high "terminal" speed attack upon its target.

In addressing the problem of multiple targets, ("number" in the original list) it became quickly apparent that the threat could have density in both space and time. Thus, the type of "counter" mounted to raids of different sizes and time/spatial separation was quite different. These threats must be allowed to be accounted for separately or together.

"Size" quickly proved to be a totally inadequate description of the "visibility" of the threat to sensors and was quickly replaced by "signatures". Thus the list had changed, over a period of research and refinement as follows;

Air Threat Elements

SPEED	In flight speed
	Terminal speed

NUMBER	Target density (time)
	Target density (space)
ALTITUDE	Engagement envelope
SIZE	Signatures
DECOYS	Decoys

In the work on the subsurface threats there were like decisions to be made which will be discussed to show some of the early discisions necessary for applicability or magnitude considerations.

At the stage just reached in the listing of important "air threat elements", the applicable "subsurface threat elements" were assumed as follows:

Subsurface Threat Elements

SPEED

RANGE

SIGNATURES	Radiated noise
	Acoustic cross section
DECOYS	

In comparison to the air threat development at the same stage, some significant differences are apparent and should be explained. There is no subsurface counterpart to either altitude or density. In the case of depth (subsurface analogy to air altitude) detection or destruction of subsurface threats was assumed to not be affected, to a first order level, by the depth of the target. This is a good example of the type of assumption which may be completely reasonable at a certain technology level (point in time) or for a specific type of analysis, but which must be clearly and completely documented. Such documentation is mandatory so that, should the factors justifying or allowing such a simplification be altered for any reason, the model can be reconfigured to include the new and now driving consideration. In our example the omission of threat density for subsurface threats reflected current tactics of single ship action, vice World War II wolf pack type operations. Such a methodology even today may be highly suspect for mine field operations. Speed is included in the list because there is a wide range of relative target speeds. That is to say that

the weapons used to counter such threats are, typically working on the extremes of their capabilities.

The remaining sections of the threat/environments developed to equal degree as those just discussed were then:

Surface Threat Elements

SIZE

RANGE

SIGNATURES

DECOYS

Size was distinct from signature to account for survivability differences between vessels. Most existing algorithmns for survivability are based on overall length of the vessel in question. Note that speed is not included for surface threats. This is because the relative speed range of all possible surface threats is so small compared to the typical weapons used to counter it.

Land Based Threat Element

Land based targets are included as a significant factor in payload requirements because the destruction of them is a current mission of some U.S. Navy surface vessels. They are, in effect, an "anti-threat".

SIZE

RANGE (TO)

HARDENING (the degree of protection provided the site)

Jamming Elements

NOISE (electromagnetic energy density)

CHAFF (physical interference with electromagnetic transmission by use of metal foil ribbons or pieces)

Weather Elements

VISIBILITY (unaided vision)

ELECTRICAL Disturbance (lightning, sunspots, etc)

TEMPERATURE

SEAS (height, period, direction)

As might be expected, the next stage in the "top down" development process was to "brainstorm" the elements which directly and significantly effected each of the threat area elements. For example, it was necessary to determine what factors "defined" the signatures of a surface threat. A good initial approach was to identify such signatures by type transmission medium, i.e. air or water borne and to further break down these mediums by the types of energy transmitted within them:

Air Borne

Electromagnetic (energy emitted from on board equipment)

Visual (reflectivity, color, roughness)

Heat (infra red energy emitted)

Noise (acoustic, air borne; used in detection only)

Radiation (sub-atomic particle air borne)

Water Borne

Radiated Noise (generated in the operation of the platform itself)

Sensor Noise (acoustic, water borne, from sensors)

Radiation (sub atomic particle, water borne)

Wake (physical disturbance to normal ocean conditions)

It is at this stage that we are truly making some progress toward our goal ; the identification of all major independent variables defining the performance of a surface combatant.

This is an excellent place to point out one of the more basic errors made and the reasons for it. One of the air threat element identified was engagement envelope. This attempt to describe the threat in terms of the magnitude or means of the counter to that threat. In other words we were artifically defining both the threat and some of the parameters describing our counter to the threat by defining the

volume of space around out ship which we would "defend". The effect was to be describing the payload required in terms of desired or precieved performance as an input. This is not what the model was developed to accomplish. The idea was to input (or define) what must be countered by the combat systems payload and have the model, through a fully developed and broadly considered program provide appropriate means to actually "defeat" the inputed threat. Therefore, this approach was abandoned and the orignal premise of definition by need, not means was begun for the air defense problem. The final list can be foundstarting on page IAI of the Appendix.

Another major omission of the threat/environment section as thus far developed was the omission of the difference between weapon and weapon platform as distinct but related factors. It was not sufficient to address, for instance, attacking missiles themselves. It is entirely possible and, in fact, most desirable to disrupt the air borne threat by "defeating" the weapons carrying platform prior to weapons release. We must, therefore, provide within our model, for the total of all elements which make up the weapon, the weapons carrier and finally the two together. This error of omission would be fundamental.

From this level of detail on, the major problem was of flow - cause and effect of each stage upon the other. The subsection of the example threat and environment menu which was fully developed was the "surface threat". A detail listing of all developed menus is included on the first page of the appendix. The next chapter will discuss this subsection in greater detail.

CHAPTER 4

DEVELOPMENT OF THE OBJECTIVE FUNCTION

This chapter will offer the methodology for the development of the function used to assess the design. Each menu string in this model was designed to establish a hierarchy of parameters. That is within a given string, the elements defining a parameter are, hopefully, "downstream" of the things they are defining. However, at each menu level there are perhaps as many as 8 to 10 different parameters of equal status, all defining the next higher menu item. For example, returning to our example menu of chapter 2, we see that there are 4 possible weapons choices for the designer. How would the designer (model user) choose how many of each type weapon should he incorporate within his vessel? The ability to choose the proper or desired combinations of such things as fire power, speed, endurance, survivability or any of many other characteristics is essential. It must be remembered that, in general, these characteristics compete for vessel resources such as space, weight or manpower within a design. The remainder of this chapter will discuss two possible methods, for singular or combination use, for this important question, specificially; given that the model (or any model) has identified the pertinent independent variables in naval ship design. How do we decide how much of

each is best? Or in other words; given the decision variables; what is the objective function?

The two techniques offered will be;

A. Utility Theory

B. Artifical Intelligence

UTILITY THEORY

We will demonstrate utility theory rather than define it. Things are "worth" more or less to an individual (or decision making group) depending upon the circumstances at the moment of evaluation. Take something as seemingly well established as the worth of a dollar. If you have $50.00 in your pocket, a dollar does not necessarily have too much value. If, however,you only need $.60 to ride the subway, but have no money at all, a dollar is something you could really appreciate One way of explaining this is to think of the utility of a dollar in each case. Another dollar, if you have fifty, is not too useful to your desire to go home. In the latter instance, that dollar has great utility if you want to avoid walking.

Utility theory is one important consequence of the axioms of rational behavior. A person who accepts the axioms

wishes to make his own decision processes consistent with them. To do so, he must always select decisions so as to maximize the expected utility of their outcome. The fact that it is the expected value of his utility which he must maximize is a consequence of the laws of logic themselves.

We will initially limit ourselves to the case where a single quantitative attribute, x, is considered by the decision maker to be an adequate description of the possible total consequences of his decision problem. Also, for simplicity, we first assume that the decision maker prefers larger values of x to smaller values. These restrictions (single numerical attribute, preference for the larger of two values of that attribute) will be removed later.

Reference Lotteries and Indifference Probabilities

Let x_1 , x_2 ,.. be the particular values of our single quantitative attribute, x, which apply to the consequences of the decision problem. Let $x^{\star}$ be some quantity as large or larger than the largest of the x_i's and let $x_{\star}$ be a quantity as small or smaller than the smallest of the x_i's. To determine the utility of each x_i (and therefore of the consequence described by x), we first establish the reference lottery of the form shown in Figure 4.1, such that the deci-

sion maker is indifferent between ownership of this lottery and obtaining the consequence of value x . This requires the measurement of $p(x_i)$, called the "indifference probability" for a consequence of value x_i.

A utility $U(x_i)$ can then be assigned to each consequence such that

$$U(x_i) = k1 + k2\ p(x_i)$$

where k1 is any constant and k2 is any positive constant. For instance, if we set k1 = 0 and k2 = 1, we may use the indifference probability itself as the measure of utility for any consequence.

Operationally, the procedure is not so useful, because it is difficult to assess the $p(x_i)$'s. A decision maker finds it hard to distinguish between probabilities like 0.13 and 0.17, for example, since one does not have a intuitive feeling for many probabilities other than 0.5. In the next section, we demonstrate a method for obtaining the utility of consequences without requiring the direct assessment of probabilities.

Our basic concept is to assess the utilities of a few consequences and plot these on a graph with $U(x)$ as the ordinate and x as the abscissa. We may arbitrarily assign utilities to two consequences for reference. Let us set

$u(x1) = 1$

and

$u(x0) = 0$

where $x1$ must be preferred to $x0$. (This normalization is equivalent to specifying the values of $k1$ and $k2$). Then we take the lottery in Figure 4.2 and find the value of x, call it $x.5$, for which the decision maker is indifferent to the lottery. The utility assigned to $x.5$ must equal the expected utility of the lottery so

$$U(x.5) = 0.5\,U(x1) + 0.5\,U(x0) = 0.5\ .$$

This gives us a third point on the utility graph in Figure 4.3. Our technique allows us to obtain the utility of a third consequence $x.5$ relative to the utilities of $x1$ and $x0$ which were set to establish the origin and unit of measure of $U(x)$. In obtaining $x.5$, we were able to keep all the probabilities encountered equal to 0.5.

The obvious question is "how does one get x.5?" This requires an interactive procedure, where the decision maker must state his preference between the specified lottery and a consequence. For instance, we would choose an amount x_a and ask whether the decision maker would prefer obtaining x_a for certain or particiating in the lottery shown in Figure 4.4. Regardless of which is preferred, we should be able to identify whether x_a should be increased or decreased to find the amount x.5 such that the decision maker is indifferent between it and the lottery. For example, it might be obvious that $x.5 > x_a$. Then when a second consequence x_b is compared to the lottery, we may learn $x.5 > x_b$. Such information will bound the true value of x.5. If one continues in the manner, the value of x.5 will be found.

An Example

Let us illustrate some of these ideas with an example. Suppose we wish to assess your utility for all monetary consequences between zero and one thousand dollars. You can think of these values as possible changes in your net assets. Since you would probably agree that \$1000 is preferred to \$0, we can arbitrarily set the origin and unit of U(x), where x is a particular change in assets, by U(0) = 0, U(1000) = 10. Our next step is to determine the amount of

assets for sure which you feel is the least amount for which you would agree to sell the lottery shown in Figure 4.5. That is, we want your certainty monetary equivalent for this lottery. Suppose you decide it is \$400. Then the utility which is assigned to \$400 must equal the expected utility of the lottery, since they are indifferent and expected utility is our measure of preference. Hence, $U(400) = 0.5\ U(1000) + 0.5\ U(0) = 5.0$. We continue the assessment of your utility function. Let us attempt to find your certainty equivalent for the lottery shown in Figure 4.6. If this amount is \$180, then the utility assigned to \$180 must equal the expected utility of the lottery. So $U(180) = 0.5\ U(400) + 0.5\ u(0) = 2.5$. Next we assess your certainty monetary equivalent (CME) for the lottery shown in Figure 4.7. Suppose your response is \$650. We have: $U(650) = 0.5\ U(1000) + 0.5\ U(400) = 7.5$. The idea should be clear by now. Let us plot a graph of $U(x)$. From the last five equations we have five points on that graph. The curve in Figure 4.8 is drawn through those points and represents your utility function for any increase in net assets from 0 to 1000 dollars. From the curve, we can see, for example, that the utility of \$700 is 8. That is, $U(700) = 8$. Similarly $U(500) = 6.3$ and $U(200) = 3.0$.

Some Characteristics of Utility Functions

There are many curves which we could have drawn through the assessed points in Figure 4.8. For instance, we could have chosen to use linear segments to connect adjacent points, to use regression analysis to find the best fit quadratic curve, or to "wiggle" any curve with ups and downs through the given points. In this section, the problems of choosing appropriately shaped curves is addressed.

Rather than just evaluate some points and smooth in a curve, it seems reasonable to first try to obtain the general shape of the utility function. This structure of the utility function can be specified by ascertaining whether or not the decison maker's preferences satisfy certain criteria. Each of these criteria puts a restriction on the form of the utility function. A useful technique is to determine the general shape of the decision maker's utility function by obtaining a qualitative expression of his preferences, and then to choose a particular utility function satisfying the general shape requirements which is also consistent with a few carefully assessed values of U(x).

Assessing utility functions is perhaps more of an art than it is a science. The success one has in such attempts is closely linked with the analyst's ability to communicate with the decision maker -- to indicate the importance of this process, to enlist his support, and to make him feel comfortable with the assessment procedure.

For discussion purposes, the assessment procedure might be divided into five steps:

1. Preliminaries to actual assessment.
2. Specifying the relevant qualitative characteristics.
3. Specifying quantitative restrictions
4. Choosing a utility function
5. Checking for consistency.

Preliminaries to Actual Assessment

Before beinning the assessment of a utility function, the concept of decision analysis should be discussed with the decision maker. Thus, he should realize the purpose in assessing his preferences and hopefully be sufficiently motivated to think hard about his feelings for the various consequences. It should be made clear to the decision maker that the preferences of interest are his -- that they repre-

sent his subjective feelings -- and that there are no objectively correct preferences. At any time if the decision maker feels uncomfortable with any of the information he has offered about his subjective feelings, it is perfectly all right -- in fact, necessary for the correct analysis -- for him to change his mind. This is one of the purposes of decision analysis, to require the decision maker to reflect on his preferences and hopefully straighten them out in his own mind.

Specifying the Relevant Qualitative Characteristics

The qualitative characteristics we are interested in are monotonicity and attitudes toward risk. To ascertain whether a monotonicity condition is appropriate is quite simple. One asks the decision maker which is preferred between x1 and x2, where x2 > x1. Probably you, the assessor, would expect a certain answer to the question based on your own understanding of the consequences. If x2 is prefered, you would tend to think preferences are monotonically increasing in attribute x. You would then just ask whether more of the attribute is always preferred to less of it.

To check for risk properties, you might divide the range of the attribute as illustrated in Figure 4.9. We would ask the decision maker whether he prefers the lottery in Figure 4.10 or its expected value x_c for certain. Note that this lottery covers the complete range of the attribute for the problem at hand. If x_c is preferred, we are inclined to think the decision maker is risk averse; if the lottery is preferred, he is likely risk prone. To check subranges, we ask for preference between the lottery in Figure 4.11 and its expected value, x_b. We also ask the decision maker's preference between the lottery in Figure 4.12 and its expected value, x_d . If the certain amounts are preferred here, as well as with the first lottery, we will probably find it reasonable to assume the decision maker is risk averse.

If sometimes the lottery is preferred and sometimes the sure consequence is preferred, we would need to check further to see whether the decision maker was risk prone in some region of x and risk averse in another, or whether he had made an error in his initial responses.

Specifying Quantitative Restrictions

To specify quantitative restrictions, we perform the assessment of some points on the decison maker's utility curve. We have already shown how to do this by assessing the certainty equivalents of a few lotteries. There are a couple of pragmatic points to keep in mind, however. First, the consequences used in the questioning must be meaningful to the decision maker. Secondly, the spread of consequences in 0.5 - 0.5 lotteries must be large enough to be meaningfully different. That is, if we are talking about a utility function for $0 to $1000, it is not very meaningful to ask questions about the certainty equivalent of a lottery such as the one shown in Figure 4.13 since there would be little perceived difference between the $500, $520 and the certainty equivalent.

Choosing a Utility Function

Once the qualitative characteristics have been specified, we will be able to select a parametric class of utility functions which satisfies these properties. Let us designate this as $U(x/\lambda)$ where λ represents the parameters. We would expect at most three parameters to allow a suitable representation of any utility function.

Then if x3 is the certainty equivalent for the lottery shown in Figure 4.14 we know $U(x3/\lambda) = 0.5\ U(x1/\lambda) = 0.5\ U(x2/\lambda)$ which gives us one equation with the number of unknowns equal to the number of parameters. Using such certainty equivalents, we obtain the same number of equations as parameters, and then solve the set for the parameters. This will provide us with a utility function.

Checking for Consistency

There are many different consistency checks which can be used to detect "errors" in the decision maker's utility function. By an error, we mean the utility function which we have assessed for him does not adequately represent his true preferences. There are a variety of ways to ascertain whether certain qualitative characteristics, such as risk aversion, hold for a particular utility function. One way can be used for a check on the results of another, etc. One generally useful check involves asking the decision maker his preference between any lottery and any consequence, or between two lotteries. In both cases, the expected utility of the preferred situation as calculated from his utility function must be greater in order to be consistent. Whenever the analyst feels uncomfortable about any aspect of the

decision maker's utility function, it would be useful to check this aspect and make any appropriate adjustments.

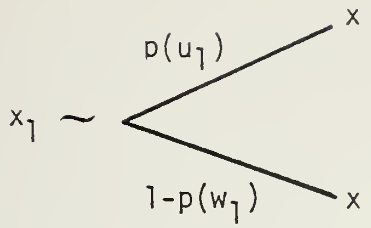


FIGURE 4.1

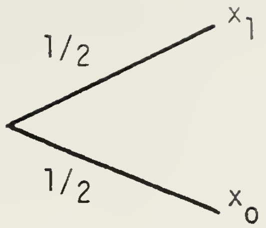


FIGURE 4.2

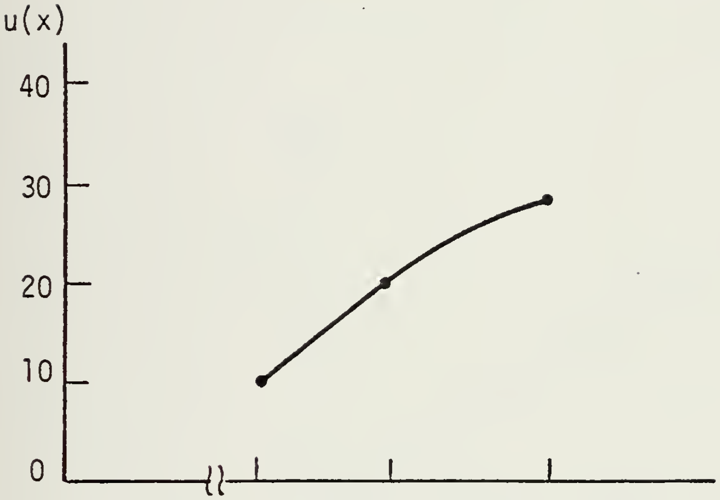


FIGURE 4.3

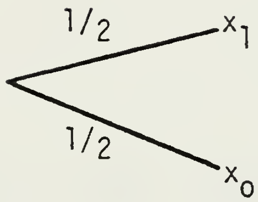


FIGURE 4.4

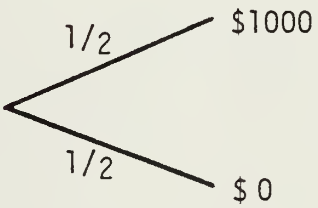


FIGURE 4.5

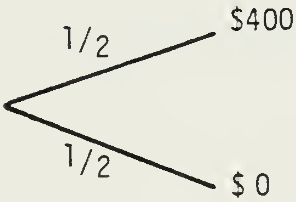


FIGURE 4.6

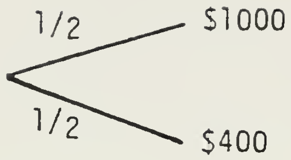


FIGURE 4.7

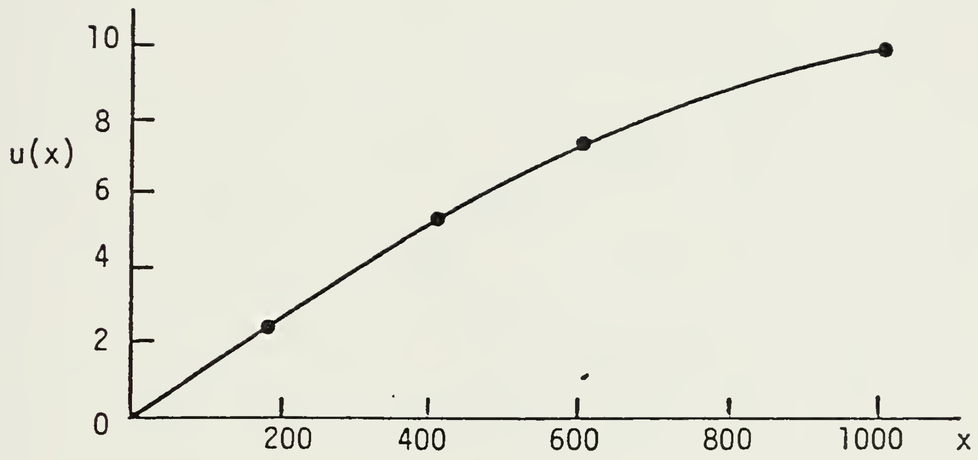


FIGURE 4.8

FIGURE 4.9

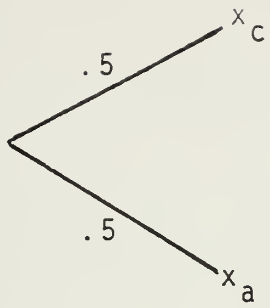


FIGURE 4.10

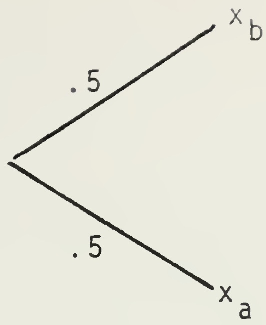


FIGURE 4.11

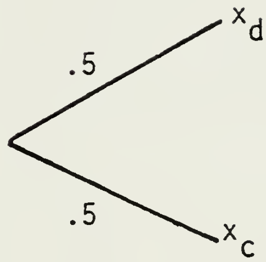


FIGURE 4.12

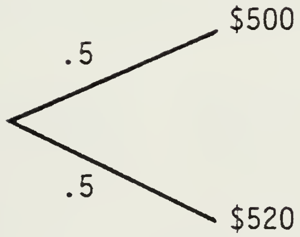


FIGURE 4.13

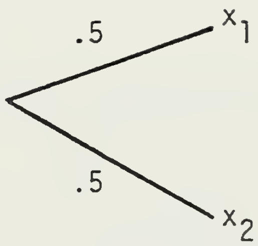


FIGURE 4.14

MULTI-ATTRIBUTE UTILITY

Ships, like other large systems, have many attributes In general, the value of any design is seen to be some U(x1, x2,...xn), where x1 is a single attribute. Our next goal will be to assess and measure U(x), so that alternative design with different x, can be ranked analytically. This ranking should be somehow responsive to both the underlying attitudes toward varying amounts of each attribute and the relative importance of different attributes.

When many attributes are considered in project evaluation, it is commonly assumed that:

$$U(x) = \sum_i k_i U_i[x(i)] = \sum_i a_i x_i$$

That is, utility is additive and linear.

In particular, traditional benefit-cost analyses simply assign a constant dollar value (a_i) per unit of each non-monetary attribute, and then add up the resultant benefits. Individual preferences are summed up by converting all desires into a "willingness to pay" for a good or service, a process that in general favors the wishes of most well-to-do of the decision makers. The consequences of this fact are significant to the national naval budget process.

The most interesting of cases of single-attribute utility functions are distinctly non-linear, so the simplification of $U_i\ (x_i)$ to $a_i\ (x_i)$ is not appropriate. Given non-linear utilities, however, it is then permissible to derive U(x) as

$$U(x) = \sum_i k_i\, U(x_i)$$

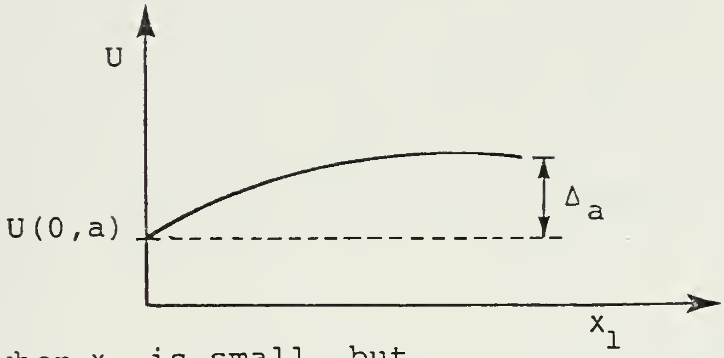
Certain sophisticated benefit-cost analyses, for example, use nonlinear demand functions, and then add up the benefits derived from each attribute.

However, consider the following example:

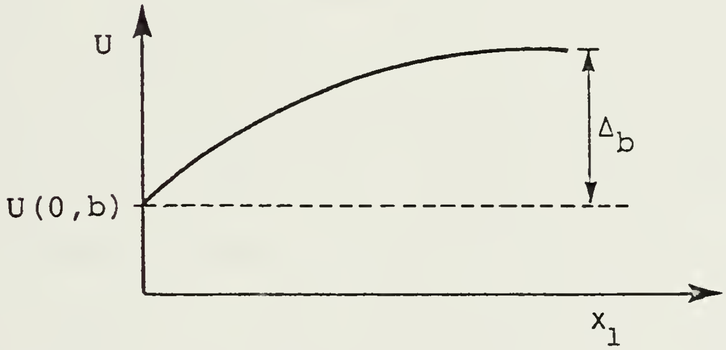
x1 = endurance range

x2 = maximum speed

Obviously, the importance of each of these factors will not be independent of the other, at least to many observers. For example, the significance of maximum speed is very much damaged by endurance. Therefore, the difference between the utility of low speed and that of a very high speed is greater if the endurance is higher.



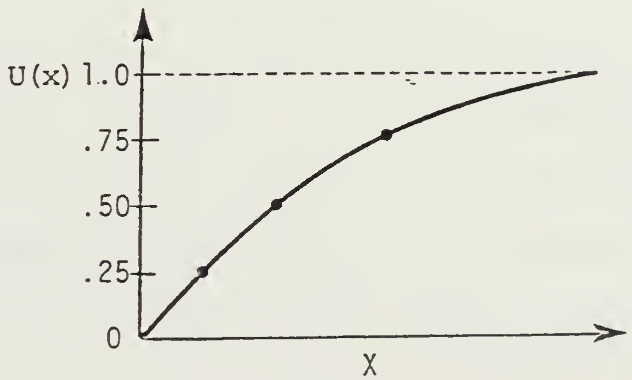
when x_2 is small, but



when x_2 is large

Note that $\Delta b > \Delta a$, which can not be duplicated by an additive model, in which $U(0,x_2)$, x_2's contribution to utility, may move up and down as x_2 changes, but, Δ, x_1's maximum contribution to utility, must be constant, regardless of the value of x_2. Note that $U(x_1)$ is not depicted as being linear, either.

Since we have discarded the linear and additive assumptions for multi-attribute utility functions, you may wonder why we do not just estimate utility directly, as we did for single-attribute utilities: choose the endpoints (U=0, U=1) use a 50/50 lottery to determine the utility midpoint (U=.5), repeat to find the quartiles (U=.25, U=.75), and draw a smooth line through the points. In three questions, we determine five points on the utility function, and with some restrictions to ensure the curve is monotonic to assure a smooth function, we can derive a reasonable approximation of the shape of that function.



However, when we attempt to extend this methodology to multi-atttibute situations, we run into the famed Curse of Dimensionality. In two dimensions, we would presumable want to know the utility of at least five points on each axis and their intersections in the planes: Now there are 25 points, of which only two are fixed by convention (U=0, U=1). If the determination of each point requires one question, 23 questions are necessary to approximate the surface. Three attributes require 123 questions, four demand 623, and five necessitate 3123 questions. Decent results would be unlikely beyond 2 dimensions: even the most cooperative decision maker will be hard pressed to answer more than a hundred lottery questions thoughtfully. Furthermore, under the proposed assessment technique, the maximum possible distance between a point of interest in the attribute space and the nearest point for which the utility has been assessed is proportional to the square root of the number of attributes: assessment becomes both more difficult and less accurate as dimensionality increases.

Theoretically two approaches are possible to solve the multi-attribute problem. As we demonstrated above, the first is an exhaustive comparison of alternatives; the large number of assessments means this method has little or no practical merit. The second approach employs behavioral

assumptions to approximate the exact utility function; the decision analyst uses these behavioral assumptions together with a few assessments to model the preferences analytically.

This second approach is further divided into two schools of thought. The Harvard-MIT school restricts the utility function directly through "independence" assumptions about the preference between subsets of the attributes. The Stanford school separates the utility assessment process into two stages: first, the ordering of trade-offs under certainty among the attributes and, second, the assessment of a risk preference function on one "numeraire", or rank order, for the deterministic ordering derived in the previous stage. The basic research for that work is contained in the Ph.D theses of D. Boyd and Thomas Green at Stanford. The remainder of this discussion provides an overview of the Harvard-MIT approach.

The Harvard-MIT method simplifies the problem but not as severely as the linear additive model first discussed. The utility function , however, is still decomposed:

$$U(\underline{x}) = f\left[U_1(x_1),\ U_2(x_2),\ .\ .\ .\ U_n(x_n)\right]$$

We still retain the individual $U_i(x_i)$, each obtained by asking 3 questions per rather than approximating them with a linear function. Furthermore we will find some more sophisticated way of combining the $U_i(x_i)$ than simply adding them up. Specifically we will assume

preferential independence

utility independence

Preferential independence is an ordinal quality the order of preferences (involving x_1 and x_2 is independent of other attributes (x_3, . . . x_n); crudely, the choice between two attributes is the same regardless of the level of other variables. Specifically, if one set of attribute levels (x_1^a, x_2^a) is preferred to another set x_1^b, x_2^b) when the other attributes have values (x_3, x_4, . . . x_n), then (x_1^a, x_2^a) is still preferred to x_1^b, x_2^b), even though the other attributes take on different values (x_3^1, x_4^1, . . . x_n^1). Symbolically:

$$(x_1^a, x_2^a) \mid (x_3 \ldots x_n) > (x_1^b, x_2^b) \mid (x_3 \ldots x_n)$$

$$\Rightarrow (x_1^a, x_2^a) \mid (x_3' \ldots x_n') > (x_1^b, x_2^b) \mid (x_3' \ldots x_n')$$

Here is an example which illustrates the meaning of preference independence:

CASE A	CASE B
MAXIMUM SPEED	CREW COMFORT
a_1 = RESOURCES NOT USED	b_1 = NOISE LEVEL
a_2 = MANEUVERABILITY IMPROVEMENT	b_2 = VIBRATION LEVEL
a_3 = REACTION TIME IMPROVEMENT	b_3 = LIGHTING LEVEL
a_4 = TONS OF STEEL AVAILABLE	b_4 = CROWDING INDEX

IF WE KNOW

$$\begin{pmatrix} a_1 = 10{,}000 \\ a_2 = 10\% \end{pmatrix} > \begin{pmatrix} a_1' = 6{,}000 \\ a_2' = 20\% \end{pmatrix} \qquad \begin{pmatrix} b_1 = 70\text{db} \\ b_2 = 10\text{db} \end{pmatrix} > \begin{pmatrix} b_1' = 60\text{db} \\ b_2' = 30\text{db} \end{pmatrix}$$

GIVEN THAT

$a_3 = 15\%$ $\qquad$ $b_3 = 1.0$

$a_4 = 500{,}000$ $\qquad$ $b_4 = 53$

THEN GIVEN

$a_3 = 50\%$ $\qquad$ $b_3 = 75$

$a_4 = 100{,}000$ $\qquad$ $b_4 = 27$ (or any other such combination)

PREFERENCE INDEPENDENCE IMPLIES THAT
IT STILL HOLDS THAT

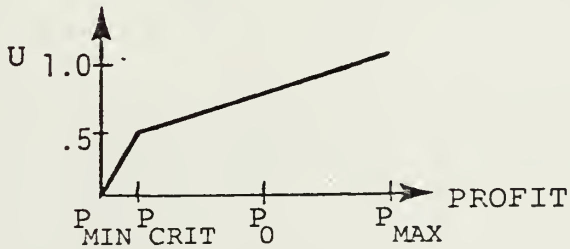
$$\begin{pmatrix} a_1 = 10{,}000 \\ a_2 = 10\% \end{pmatrix} > \begin{pmatrix} a_1' = 6{,}000 \\ a_2' = 20\% \end{pmatrix} \qquad \begin{pmatrix} b_1 = 70\text{db} \\ b_2 = 10\text{db} \end{pmatrix} > \begin{pmatrix} b_1' = 60\text{db} \\ b_2' = 30\text{db} \end{pmatrix}$$

> : The ordered pair is preferred

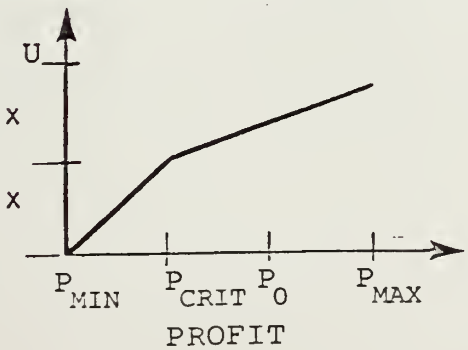
On the other hand, diet problems (among others) readily present counter examples to preference independence.

While preferential independence does not hold in every case, it does show up in many practical situations. Even where it is not true of one statement of a problem, the problem can frequently be re-formulated in terms of variables that are preferential independent.

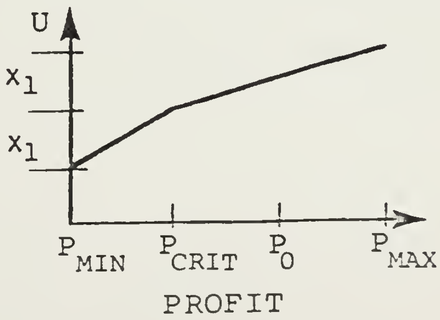
The second and much tougher assumption, utility independence, specifies that the shape of U(x) as x_i changes (with x_i ($i \neq j$) held constant) is independent of the level of the x_j . With respect to design of a ship, for example, if the utility curve looks like:



then utility independence allows the function to look like:



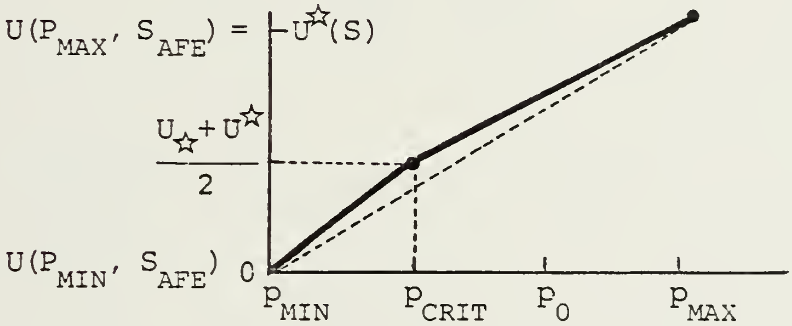
or



if safety is poor, depending on U(Pmin, Safety Poor) and U(Pmax, Safety Poor): in each case, half of the utility change takes place in the first third of the profit range. But it can not look like:

or

Our U(Profit) can be expressed in a single graph as:



Once $U^{\star}$ and $U_{\star}$ are determined (as a function of safety), the utility curve for profit is fully defined. If we know the utility of some amount of profit P_0, given safety level 1, what does that tell us about $U(P_0)$, given safety level 2? Our utility independence assumption requires that $U(P_0 S)$, always be some fixed proportion of the distance from $U_{\star}$ to $U^{\star}$ (S).

Therefore,

$$\frac{U(P,S) - U_{\star}(S)}{U^{\star}(S) - U_{\star}(S)} = \text{Constant}$$

so letting $S = 1$ and $S = 2$,

$$U(P_0,2) = \frac{U(P_0,1) - U_{\star}(1) \cdot (U^{\star}(2) - U_{\star}(2)}{U^{\star}(1) - U_{\star}(1)} + U_{\star}(2)$$

or

$$U(P_0,2) = U_{\star}(2) - b_{1,2} \cdot U_{\star}(1) + b_{1,2} \cdot U(P_0,1)$$

where

$$b_{1,2} = \frac{U^{\star}_{(2)} - U_{\star}(2)}{U^{\star}_{(1)} - U_{\star}(1)}$$

or

$$U(P_0,2) = a_{1,2} + b_{1,2} \cdot U(P_0,1)$$

where

$$a_{1,2} = U_{\star}(2) - b_{1,2} \cdot U_{\star}(1)$$

Now $a_{1,2}$ and $b_{1,2}$ are only functions of safety so,

$$U(P_0,2) = a_{1,2} + b_{1,2} \cdot U(P_0,2)$$

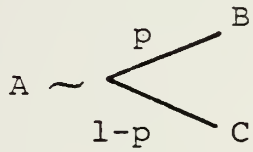
Therefore,

$$U(P,2) = a_{1,2} + b_{1,2}\ U(P,1)$$

for all P, simply a linear transformation of $U(P,1)$.

Equation (A) allows us to prove a very important point: utility ("shape") independence implies that preference between lotteries in one attribute is not affected by the level of other attributes.

For example, given:



Profits A,B, or C
Safety = 1.0

we know

$$U(A,1) = p \cdot U(B,1) + (1-p)\, U(C,1)$$

to show that

$$U(A,2) = p \cdot U(B,2) + (1-p) \cdot U(C,2)$$

that is, the indifference between A and the lottery is maintained when safety changes, we simply note (dropping the subscripts):

$$U(A,2) = a + b \cdot U(A,1) = a[p + (1-p)] + b[p \cdot U(B,1) + (1-p) \cdot U(C,1)]$$

$$= p[a + b \cdot U(B,1] + (1-p)[a + b \cdot U(C,1]$$

$$= p \cdot U(B,2) + (1-p) \cdot U(C,2)$$

And that's why it's called utility independence!

We have discussed preferential independence two attributes with respect to all other attributes, and utility independence of one attribute with respect to all others. The independence concepts can also be defined in terms of other numbers of attributes -- but such properties need not be demonstrated in order for the following technique to be justified.

Artificial Intelligence

The second technique offered will be called broadly termed artificial intelligence. Although it is certainly true that a computer can not think, it is foolish to overlook or ignore the computer's ability to recall out the actions, good and poor, taken by others. In simplest terms decision maker acts, not only on his own opinions, but upon the preceived or known actions of thers in similar circumstances. The field of "artificial intelligence" is little more, in this least sophisticated form, than pathed actions made by the computer based on a statistical preference of previous human decision makers. Although this research will not attempt to develop the scientific basis for artificial intelligence aided decision making, it will stress one opinion.

To use this discipline a foundation of previous decisions in similar circumstances is required. Since individual level decisions are being made in existing combat simulation and ship synthesis models, the retention and cataloging of them should be started.

It is believed that both utility theory and artificial intelligence might prove significant aids to our unresolved,

but pivotal problem. The ultimate decision of which quanitates and in what proportions should be included in a specific design. The purpose of each is the same. Show the decision maker how to include his preferences within a decision toward a consistently defined problem. It is this need for a common definition of the problem which must be solved. It is offered that we have multi attribute utility theory to address the number of elements and, perhaps, artificial intelligence to assist in the problem of multi decision makers. The two techniques may prove ultimately complementary to the resolution of the appropriate ship design objective function.

CHAPTER 5

THE ASSET SHIP SYNTHESIS MODEL

A method must be found to translate the hardware payload and the conceptual platform into first, comparable terms and second, into a first approximation of a ship. In this project the following characteristics for this translation were considered desirable.

1. Executable within DEX software.
2. State of the art model
3. Interactive
4. Able to take full advantage of this models the framework of the model we have proposed.

The most efficient method of achieving the second of these objectives was to find an existing ship synthesis model which was developed to to incorporate many if not all, of the aspects we identified in previous chapters as essential. with the limitations of other models discussed in chapter 1. Independently to this research, the project team was introduced to the directors research team at the David Taylor Model Basin in Carderock, Md. This group was actively involved in the development of a ship synthesis model intended to provide for the analysis of the effect of technological changes upon a ship design at the feasibility

stage of the design process. The "Carderock" model is excellent for the purposes of our effort. This is because it can be initiated by the fewest and most elementary of descriptive parameters. In addition the Carderock model allows for development/modification of all included concepts in extensive depth. Because of the significant efficiencies to be gained by using an existing model in our project, and DEXs' ability to accomodate existing analysis code with minimum modification it was decided to develop the combat effectiveness model with the explicit intention of using ASSET as the vessel synthesis technique.

The Carderock model is called Advanced Surface Ship Evaluation Tool (ASSET) and is an interactive computer program for use in preliminary evaluation of frigate, destroyer, and cruiser-type ships. It will ultimately encompass virtually all major technologies that are relevant to the design of such ships, including hullform sizing, hydrodynamics, propulsion, structures, weights, hydrostatics, cost, manning, space requirements and survivability. The program features design synthesis capability, options, including interactive graphics and use of either English or metric units. ASSET is primarily intended as an interactive tool for providing timely resuts to engineering queries.

ASSET was designed to avoid the pitfalls typical of programs of similar scope, such as extreme difficulty of use, poor responsiveness to engineering queries, and inadequate technical depth in the multidisplined environment. The ASSET engineering modules for ship design are manipulated by the user via a small yet powerful set of commands. ASSET was designed to execute interactively via a teleterminal to provide desk-top convenience while avoiding delays inherient in batch (card) oriented systems. Finally, the ASSET engineering tools represent most of the major technologies that are relevant to destroyer-type ships. ASSET consequently allows an increase in engineering productivity during the ship design cycle by allowing the user to apply the ASSET engineering tools in an easily-used, responsive, yet technically sophisticated environment.

Use of the ASSET engineering system closely parallels the classical process of ship design. The design team begins with a set of mission requirements that the proposed ship is to accomplish. Existing design data and computational procedures are employed in an iterative sequence to derive a ship design, as exemplified by the design spiral. ASSET's value is in the automation of many of the manual processes performed in the iterative design process. Instead of manual search through lengthy residuary resistance coefficients, ASSET performs the search. Instead of manual construction

of a plot of hydrostatic righting are versus heel angle, ASSET draws the plot. Instead of manual storage of design data in notebooks, ASSET stores the data on computer disk files, from where it may be easily recalled and reviewed.

Although many of the precesses involved in the design of a ship are automated by ASSET, the program leaves the critical engineering decisions to the designer. ASSET makes no attempt to decide whether to employ waterjet or propeller propulsion, whether to use Newton-Radar or Wageningen-B propeller curves, or whether to use a three or four bladed propeller. ASSET makes no significant design decisions whatsoever. The program employs selected algorithms to perform selected calculations. The designer retains essential control of the program.

PROGRAM STRUCTURE

PROGRAM CONCEPTUAL ORGANIZATION The system is composed of five principle elements: the designer, an executive program, a series of computational programs, a ship design undergoing generation or analysis (called "current model"), and a data bank.

DESIGNER The designer is the controlling element of the ASSET system. Through a simply command language, the

designer directs execution of, or interaction between, the remaining system elements. Although capable of batch (via cards) execution, the ASSET system was designed as an interactive tool for ship engineering. Consequently, the designer typically utilizes ASSET by means of a teleterminal where commands may be entered and results of those commands immediately reviewed. Delays are thereby minimized.

EXECUTIVE PROGRAM The executive program is the ASSET system element that interprets each user command and thereafter performs each task that is required to accomplish the user instructions. The executive program is also the lone system element that can directly interact with each of the other system elements. Performance of any given user command generally involves the remaining three system elements.

CURRENT MODEL The current model element of the ASSET system is the temporal collection of data that represents the one ship design under generation or undergoing analysis. All program computations use current model data only. The current model is temporal because it exists only during execution of the program. To become permanent, current model data must be transferred to a permanent storage device.

DATA BANK A data bank has been incorporated as an element of the ASSET system for the purpose of permanent

retention of ship data. Entire current models or pieces of a current model may be stored in the data bank under a name selectable by the user. During an ASSET session, ship data may be transfered from the data bank to the current model or from the current model to the data bank.

The executive program, the current model, and the data bank can also be employed to create entirely new ships in the current model by recall from the data bank of pieces of data from different ships. For example, one can transfer ship data corresponding to the propulsion system of Ship A from the data bank to the current model and then transfer hull offset for Ship B from the data bank to the current model. The current model would thereby contain a vessel of Ship A type propulsion system but Ship B type hull.

COMPUTATIONAL PROGRAMS

The calculative function of ASSET list performed by the element that consists of eleven computational programs. Each program represents a distinct engineering technology that can be applied to the design and analysis of ships. Through a simple command to the executive program, it is given to the computational program. Following termination of the computational program, output data, selectable by menu, are displayed to the designer. Certain computational

programs also add to, or modify, the current model as part of the ship design-generation process.

COMPUTATIONAL PROGRAM TYPES Three types of computational programs within ASSET: initialization, synthesis, and analysis. The description of the programs within each type is given below.

The initialization section of ASSET consists of a single program. It utilizes simple empirical methods to calculate a variety of ship data. As its name implies, a primary function of the initialization program is to provide an initial starting point for a new design under development with ASSET. A secondary use of the initialization program is in performance of high-level, parametric trade-off studies.

Six synthesis-type computational programs exist within ASSET. Each program is concerned with a single technological area of the ship design. In contrast to the initialization program, each synthesis program utilizes rigorous analytical techniques in computation of ship data.

The third type of computational program is called analysis, of which there are four. Like the synthesis programs, rigourous analytical techniques are employed. The principal difference between synthesis programs and analysis programs

is that synthesis programs modify the current model. Analysis programs do not modify the current model, only provide additional information about it. Also unlike analysis programs, synthesis programs can be employed in an iterative loop to converge on a ship design. The process, known as design synthesis, is simply an automated traverse of a design spiral from the mission requirements to the converged upon ship design.

COMPUTATIONAL PROGRAM FUNCTIONAL DESCRIPTIONS

The function performed by each ASSET computational program is described in the following section.

INITIALIZATION

This program is normally the first program to be exercised after assembling a new ship in the current model. Data is thoroughly checked for completeness and if no fatal errors exist within the data, a mini-design synthesis process is initiated that contains geometric, hydrodynamic, propulsion, performance, and weight calculation capability. Simple empirical methods are used throughout. The calculation sequence used by this program is as follows:

1. Input data are checked.

2. Ship weight is estimated.

3. Hull is resized, if requested.

4. Auxiliary and electrical systems are sized.

5. Hullborne ship drag force is calculated.

6. Hullborne propulsion system is sized.

7. Ship range or fuel weight is calculated

8. Ship weight is recalculated.

9. If the ship weight calculated in step 8 does not equal the weight as previously calculated, the mini-synthesis cycle is repeated from step 3 until weight convergence occurs.

HULL GEOMETRY

The hull geometry program defines girder, and deck locations, and also defines superstructure and hull geometry. Hull offsets in the current model are scaled and warped to define a new fullform that meets requested physical characteristics. This program includes portions of the Navy program "Hullform Derived from Parent."

This module calculates scantling data for the ship elements defined in the current model. The calculations are based on pressure loading data which are either calculated by the program or input by the designer. Scantlings are

determined at three longitudinal locations for the hull bottom, hull sides, and weather deck. Additional scantling data are calculated for lower decks, bulkheads, frames, girders, beams, and stiffeners.

HULLBORNE HYDRODYNAMICS

The hullborne hydrodynamics program calculates ship drag during hullborne operation. Either planing hull or Taylor Standard Series drag-type calculations may be performed.

HULLBORNE PROPULSION

The module performs sizing calculations for either a waterjet or propeller propulsion system. The waterjet-propulsion system section of this program calculates engine power requirements, water-duct losses, pump size, and operating data based on given drag, duct, and pump type data. The propeller size, and propeller operating data based on given drag, gearbox, and propeller characteristic data.

FUEL/RANGE

Range performance is calculated by this program in either of two ways. The weight of fuel required to achieve a spec-

ified hullborne range is calculated or the range which may be achieved by a given ship is calculated. The calculation mode is specified by the designer. Fuel requirements for auxiliary and electric plants are also considered.

WEIGHT

The weight program calculates a detailed weight breakdown for the ship. The weight statement follows the Navy Ship Work Breakdown Structure, SWBS.(see OPNAV Inst 9100.2b, 1978)

PERFORMANCE

The performance program calculates the performance characteristics of ship designs that have been generated via the design synthesis process. Whereas design-synthesis performance calculations assume calm water and a clean ship, the performance program considers fouling effects of marine organisms, degradation of machinery with time, and sea state operation.

COST

The cost program estimates ship costs for the purpose of design tradeoffs and comparative evaluation. Both unit pro-

duction costs and life cycle costs are addressed. Simple empirical relationships based primarily on the Navy SWBS are used to estimate unit costs. Life cycle costs are estimated utilizing a variety of data.

GEOMETRY DISPLAY

The geometry module produces plots of ship geometry. Hull lines, bulkheads, decks, and superstructure can quickly and easily be assessed for correctness by the designer.

DESIGN SYNTHESIS

The design synthesis process is another step employed in the manual process of ship design that has been incorporated into ASSET. After establishment of mission requirements, the designer typically generates an initial design to serve as a starting point. This initial design may be a previously established design of similar function or an entirely new concept. Unfortunately, the initial design is seldom satisfactory. Minor or gross modifications must be performed. For example, additional cargo volume may be needed. The designer may elect to expand the hullform to satisfy this need. But expanding the hullform changes ship resistance, which impacts required propulsive power, which may demand a new power plant, which may change the amount of fuel carried

to achieve a desired range. The modified hull, propulsion plant, and available fuel impact the total weight of the ship. The initial estimate of ship displacement for which resistance calculations were previously performed may require revision, and new resistance calculations may need to be performed. The design spiral goes on and on, hopefully toward a converged design.

The key to operation of the design synthesis process is the ability of each synthesis module to modify the current model. Critical ship data in the cuerrent model such as hull lines, superstructure characteristics, hullborne drag, hullborne propulsion data, fuel/range data, and ship weights are modified during the synthesis process, each by the appropriate computational program. Convergence of a ship design occurs when two passes through the synthesis loop produce virtually indentical designs.

This project has been designed to implement ASSET through the techniques of the DEX. Initial investigation with the ASSET development team has confirmed the opinion of the team that initiation of ASSET through DEX will be relatively straightforward. It is expected that the initialization section of ASSET can be called into this model, through DEX, in as few as 4 menus consisting of approximately 15-20 design parameters.

CHAPTER 6

COMBAT EFFECTIVENESS

This section is the most important of the entire project. The development of this section focused upon the following three considerations.

Completeness

Accountability

Applicability

Completeness

The content of this section is as follows: A. the situation is defined, including; the composition of forces on both sides (this information is obtained from the current or a redefined situation obtained from section 1a "Threats and Environment" B. The operation or employment of each vessel is specified. In this sub section, the opposing forces are further defined as modeled at the moment at which an estimate of combat effectiveness is desired. The sub section will prompt the user to specify the status of each major parameter of the opposing forces. It is intended that this potentially laborious task be eased by having this specification done by default. That is, that items not high-lighted by the user are assumed to be operational and in operation to the extent of availability and performance

previously given. C. The definition of combat effectiveness is assumed to be an unspecified combination of the amount of "damage" inflicted upon the enemy and the amount of surviving capabilities of the designed vessel after the action. Each of these major combat effectiveness parameter paths is developed to the degree required by the other two considerations of this section; accountability and applicability. Note that we are, again, avoiding answering how much each of these paths might contribute to an overall definition of "effectiveness". Extensive amount of discussion with operational and design authorities indicated that such an evaluation is a function of

How the totality of overall conflict is perceived

The perceived strength of enemy in general area (potential immediate opponets)

Perceived relative strength trends of the opposing forces.

Accountability

In various areas of this model, extensive menu strings are taken, intact, from one section to be used in a higher level section. As such, these strings must be correct and concise as possible for all sections in which they are used. They should provide the difficult balance between what is necessary to sufficiently specify the problem, and the desire to limit the total number of possible decision points to simplify the execution of the model. The method used to

accomplish this trade-off was "comparision and reduction" from a higher (earlier) section to the section under development. For example, in choosing the surviving capabilities to be included in the "Combat Effectiveness" section (7), the section describing the payload (3) and the section listing the platform characteristics (5) were compared. From the gross list formed by the total of the two sections, a shorter list was formed by eliminating redundant or overlapping elements. As discussed in chapter 2, this reduction was accomplished by weighing the opinions of several war-gaming experts (most notably, John Corsey of the U S Naval War College) and personal opinions gained by the author from specific literature reviews (see the bibliography section on "Professional Publications").

As might be concluded, this is a highly subjective process with all the attendant dangers of such a generally described process. Because of this, the validity and completeness of this section should be the initial area confirmed by any future researcher in this field. Within this section, the output or product of the entire project is the most sensitive to changes in format and construction of the individually included menu items. To aid in menu accountability, a section menu to section menu listing for the section is given below.

COMBAT EFFECTIVENESS MENU	THREAT MENU

must be consistant with

"threats neutralized" (by type)	"threat type"
"threats damaged" (by type/amount/area)	"threat types"

COMBAT EFFECTIVENESS MENU	PAYLOAD MENU

must be consistant with

"self defense capabilities"	"payload; self-defense"
"force defense capabilities"	"payload; force/area defense"
"offensive threat neutralization capabilities	"payload; offensive threat neutralization capabilities"

COMBAT EFFECTIVENESS	PLATFORM CHARACTERISTICS

must be consistant with

"flag CCC capabilities"	"flag CCC capabilities

Applicability

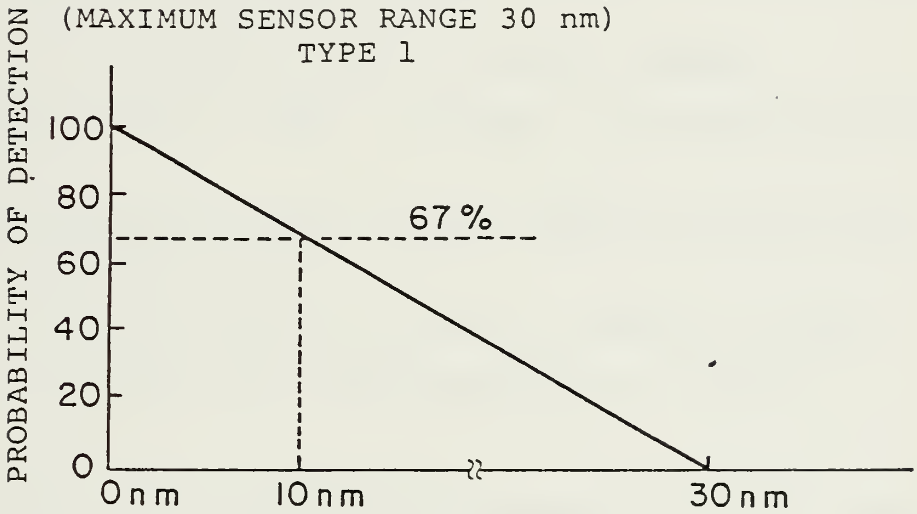
This term is used to indicate the constant responsibility for each included menu item to be necessary. There is a conflict with this desire and the stated "design philosophy" precept concerning highest level development. Because of the desire to give precedence to the design philosophy, there was been only first order efforts in the area of applicability in the model as a whole. In the Combat Effectiveness section the availability of experts and excellent references, allowed some significant "winnowing" of the section. In general, this section is designed around the existing gaming algorithms as used in this country. Many elements which would be significant to the naval architect are not significant to the combat simulator because he simply has no way to account for them.

Operation of the Combat Effectiveness Section

Once the user has defined the general situation from which he wishes to obtain an estimate of combat effectiveness, he is ready to exercise the sections computational areas. Because this area is designed to be the most innovative of the project, we will describe this translation. The sequence would proceed as follows:

DETECTION RANGE CALCULATION

GRAPHIC TECHNIQUE
(MAXIMUM SENSOR RANGE 30 nm)
TYPE 1



DETECTION RANGE THRESHOLD (67%) $\cong$ 10 nm

FIGURE CE-1

1. The setting of the conflict is established. As previously discussed, this might include, weather, other units or any other factor which could affect the outcome of the engagement as modeled.

2. The operating status of the units is defined. Here we specify the on/off status of the sensors, weapons or other equipments having a detectable signature.

3. The relative position of the conflicting forces is set. There are several range possibilities, with attendant action possibilities including;

   Outside of sensor range (by sensor system)

   Inside sensor range, outside all weapons systems ranges

   Inside sensor range, inside weapon systems range (by weapons system)

   Inside minimum weapons range (by weapons system)

4. Action is joined at the range specified in step 3

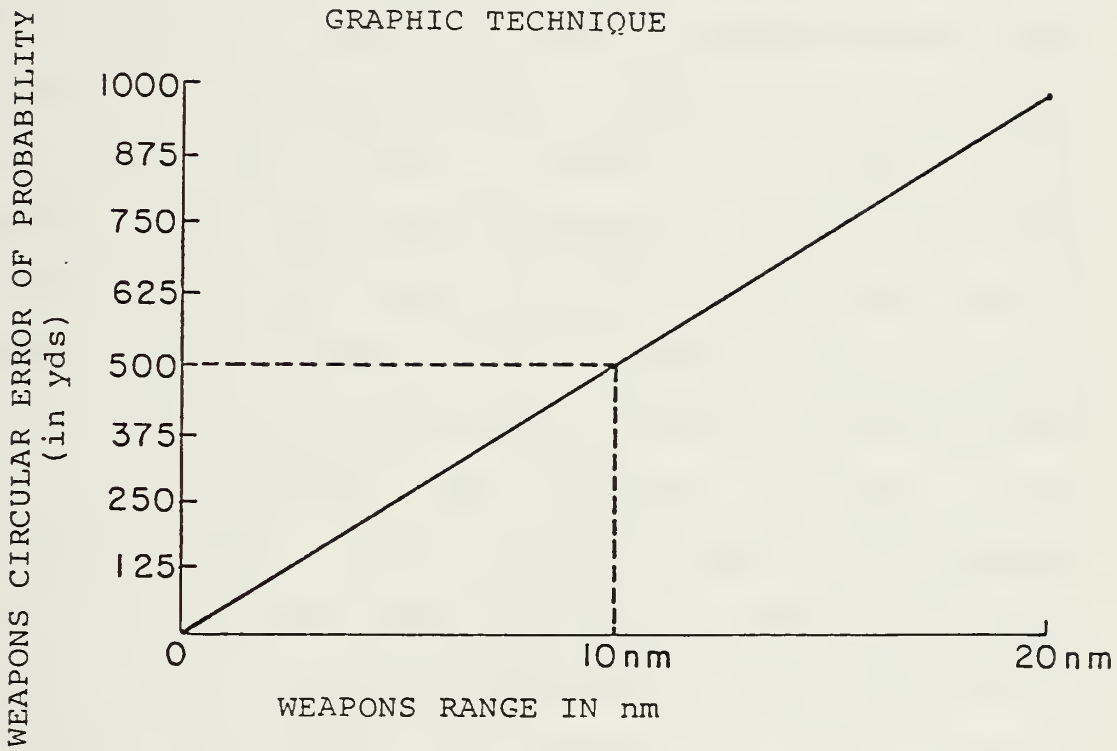
Once either unit is within the maximum dectection range of an operational sensor, the detection event must be resolved. The detection event can be looked at in two ways. The probability of detection at a given range, or the range at a given probability of detection. Since we need the range of an action to proceed to the next step in the model we will use the range at which the target is assumed to be detected by the sensor. The method used to find that range could take many forms. The most accurate might use historical information from "similar" encounters. Another technique would be to use the design specifications of the equipment. The third method might be algorithimic. This is

the technique we will use. In this algorithim, we will assume a linear "curve" describing the distribution of the probability of detection from the maximum design detection range to the minimum. See figure CE 1. This implies that the target is becoming more easily detected as an inverse, linear function of range. In addition, we will specify that, not withstanding the finite probability of a detection at any range less than system maximum, the target will be assumed detected only when the probability of detection reaches 67%. That is, in 67% of assumed cases the target was detected prior to this range. In the example on the next page, dectection will, therefore, always occur at 10nm. This assumption is not as artificial as it might appear, as most systems and systems operators do not, routinely, perform to the systems "advertised" specifications. The actual percentage threshold range is arbitrary, of course. Although a more generous threshold detection range may be specified, it is not important to the technique. An example is developed in figure CE 1 in graphic form.

Given that the detection has occured, the next operational decision would be to join or decline action. If, in the model, the defined situation, (or the users override, see chapter3 page 30) specifies action the model proceeds as follows.

CIRCULAR ERROR OF PROBABILITY (C.E.P.)
CALCULATION

GRAPHIC TECHNIQUE



AT 10 nm C.E.P. = 500 yds

FIGURE CE-2

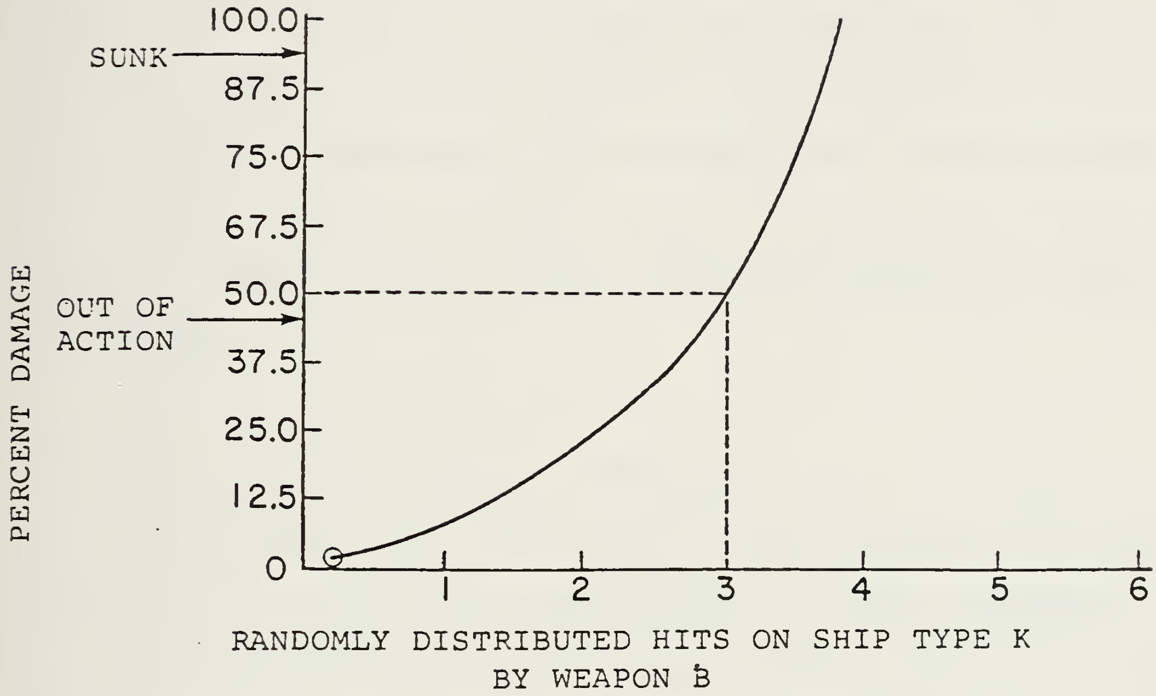
A weapons action is defined as the determination of the number of expected hits by a given weapon upon a given target at a specified range. The calculation assumes that the system is operational and the target is within maximum weapons range. Of the many possible methods of such a determination, this model will; 1. Define the length of the engagement. This will give the number of rounds fired based upon the systems firing rate (note that firing rates are not necessarily single valued). In our example, 1 minute firing with a firing rate of 30 rounds per minute gives 30 rounds fired. 2. Calculate the weapons "circular error probability" (CEP). This parameter measures the expected dispersion of warhead impact points as a function of range. In simple terms it describes the circle within which 50% of the rounds fired would be expected to land. For our example, we will use a simplified but representative algothrim, much like the sensor detection format. In our example, the input range of 10 nm, from sensor detection range is within the maximum weapons range of 20 nm and the model "opens fire". From the CEP curve , figure CE 2, the initial CEP is 500 yards. Therefore if the opponets maintain 10 nm separation, it may be expected that 50% of the 30 rounds fired, or 15 rounds, land within 500 yards of the aim point or target. Again we simplify by assuming perfect aim, but inclusion of an aim error would be a straightforward but

forgone matter. The next problem is the assessment of the effect of the hits (if any) upon the target; the damage assessment.

Damage Assessment

There are, again many methods of assessing possible damage inflicted upon a given target by a specific pattern of rounds. This model will use a percentage coverage approach. In this approach, the percentage of the CEP covered by the target (the length of the target divided by the CEP) will be multiplied by the number of rounds landing (randomly) in the CEP (up to a maximum of one). This gives the expected number of rounds landing upon the target. In normal practice, any one of several scientific techniques are used to make this number an integer. In the case of the model, we would use a random number generator with even or odds last digits determining round added or subtracted from the integer, respectively. In our example, we will assume a target length of 300 feet (100 yards). Our target "fills" 100/500 or 0.20 of the weapons dispersion (CEP) so that 0.20 times 15 rounds or 3 rounds are assumed to impact the target. Although the amount of damage inflicted by a single round is not independent of the impact point along the ships length, since the weapon dispersion is random, we will not address any difference in types of "hits". Therefore assuming a

DAMAGE ASSESSMENT
(OF WEAPON B ON SHIP A)



In our example, percent damage

50 percent (plus)

$\Rightarrow$ vessel forced to retire

FIGURE CE-3

random distribution of hits, random normal is acceptable, the type and effect of the damage might be determined by the model from a table or curve such as figure CE 3. Again the form of this curve is critical to the outcome of the conflict, but not important to the development or execution of the model. Damage curves, such as figure CE 3, exist in several places where combat simulation has been conducted for decades.

From our example damage assessment curve of figure CE 3, it is assessed that the 3 hits inflicted upon our target force it to retire. The implication is that the opponet is out of action for a period of time, but may return to action after some repairs. This type assessment (sunk, retire, etc) as results of specific damage accumulations, is very subjective but absolutely essential. It is important because it affects the operation of the opponet and thereby affect the actions and performance of both sides. This determination of elimination, temporary removal or degradation of a unit is required to permit the model to conduct multi-unit assessments.

To recap our example Our ship (P) detected opponet (K) at 10 nm by sensor A. We engaged ship K at that range with weapons system B. In 1 minute of firing, we inflicted 3 hits, forcing our opponet to retire.

This is interesting, but what was ship K doing to us in the meantime. The answer is , exactly the same sorts of things we were doing to him. Obviously, certain actions by one opponet would be precluded from execution by the outcome of actions by the other. For example, if we suffered enough damage to be sunk before the 1 minute of firing was conducted, we could not have forced our opponet to retire. This brings up the problem of time versus event modeling. In the simple cases we will describe in this model each conflict is being treated as a separate event. A more accurate depiction would permit the proportional sequencing of events to form a multi-state assessment. For the present, this model must address each change to the combat situation as a separate entity.

Measure of Effectiveness

In our example, ship P forces ship K to retire (turn back) with 50% damage to its systems. In turn, ship P suffered uncalculated damage in that same event. To state how effective P was against K, we must weigh the relative value of the two damage states of the opponets, and the actions expected to result from that damage. Thus our measure of effectiveness is the desired balance between the two different "combat effectiveness" menu branches of; A Surviving Capabilities (starting at menu page) and B. Threats neutralized (starting at menu page). This balance

must be established by the designer or user of the model. Most likely, a comparision of the different results of a number of opponets and in a number of different situations will be necessary. Methods of obtaining such a blending of seemingly conflicting outputs are offered in chapter 4. One additional note; even this extremely simple action sequence shows the advantage of internally consistant computer managed data bases over more conventional approaches.

CHAPTER 7

COMBAT SIMULATION

In this chapter we will trace an example of the combat simulation section module. We will simplify the case by the following assumptions:

1. Both forces fully defined
2. Single unit interaction
3. Minimum additional external factors (weather, jamming)
4. Fully operational units

We have chosen, as our opponents, the FFG-7 frigate class of the U.S. navy as it might be expected to be configured today, and the Krivak II frigate of the Soviet navy. This choice, as made provides

Approximate equality of

size

manning

speed

relative positon in "order of battle"; that is the relative importance of the ship class in the countrys' total naval force.

These ships are designed for different primary warfare missions (FFG-7 = AAW, Krivak = ASW). The baseline units and situation is described in table CS-1. We will demonstrate the modules capabilities by explaining its ability to

1. Model the revelent parameters of the specific situation
2. Be sensitive to changes in unit configuration operational senario.

Four alternative sets of combat effectiveness values will be attempted

1. Baseline/no harpoon missiles on FFG-7
2. Baseline/harpoon on FFG-7
3. Baseline/units at 35 nm initial range
4. Baseline/Units at 5 nm initial range

The model would retrieve the baseline Krivak and FFG-7 (Perry) from the threat (section 1A menu), and (section 5 menu), respectively. See table CE1 for highlights. Thus there, will be four cases: Harpoon/35nm, No harpoon/35nm, Harpoon/5nm, and No harpoon/5nm. In all cases the units will be initially unaware of the adversaries presence. They will, therefore, be employing an acoustic/electronic emission control scheme design intended

to optimize the respective units primary warfare mission area. Table CE-2 shows these conditions.

1st CASE (No harpoon/35nm)

In the initial circumstance we will assume, due to the range and partial emissions control posture, of both vessels, that neither ship "knows" that the other is in the immediate area. Thus, our situation would start with a detection of either unit by the other.

1. Sensor performance (detection).

Examining the two opponents sensors versus the appropriate signature levels, we might conclude the following:

Air detection - none

Surface (radar) detection - none

Electromagnetic detection - potential soviet ECM vs SPS-55 & SPS-49: potential US ECM vs DON-2 (less than above)

Acoustic detection - potential TACTAS vs soviet VDS; potential TACTAS vs soviet propulsion

DOMINANT PROBABILITY

1st assumed detection: TACTAS (convergence zone) on Krivak II at 28nm. (see chapter for assumed sensor performance algorithm: use max range of 90nm (2nd CZ)) Since no weapons are assumed to have range to exploit this

detection, situation continues until range closes to less than 15nm at which time FFG-7 launches standard missle in active/ARM (anti radiation missle) mode on Helo (lamps) solution - note that FFG-7 class would/should attempt to maintain maximum standoff if possible. Also note that TACTAS is not assumed to provide a fire control solution. The possible firing doctrine might call for a single shot with ready second round fired upon damage assessment or unacceptable first weapons telemetry data. In this situation we are going to assume a hit based upon a positive random probability less than 1.0 and an out of action status to the Krivak with 40% total systems degradation. No damage or missions interference is assessed to the FFG-7.

Considerations

If the FFG-7 is not ARM configured and if LAMPS is not able/allowed to provide fire control solution or weapons delivery (not discussed), the situation, would most likely deteriorate to a gun fight. This assumed that the sometimes accredited anti-surface capability of the SSN-14 is inaccurate. In short, the margins of the weapons systems capabilities totally dominate our solution and must be defined/specified/agreed upon to validate to outcome or specify the solution.

CASE 2 Harpoon/ 35nm

Same as Case 1 in initial aspects up to the weapons action (each side has the same sensors as case 1). Note, however, that probablistic models of detection or weapons performance might very well give a different function to the beginning of the problem). If, however, the situation is considerated constant, the following trends in performance might be expected:

LAMPS still needed for over the horizon fire control solution

Harpoon missile deployable at opening (from initial detection range) target up to 55nm

Lethality of harpoon much better than standard missile

This model would more often assess a sunk Krivak, with all that event might imply to other actions.

Outcome assessed

Sunk Krivak, Undamaged FFG-7

Considerations:

The possibility of damage to FFG-7 is much lower in this case that case 1. Thus it is a much better situation than Case 1 for FFG-7 although assumed outcomes might be considered "equal".

CASE 3 No Harpoon/ 5nm

In this instance it is assumed that the two units are together (that formal hostilities have not started) In this situation detection is assumed and valid fire control solutions are assumed to take equal amounts of time for both vessels. Even if the Krivak does not begin/or have a fire control solution before the FFG-7 the only appropriate weapons on both ships are the guns. Given the number /rate of fire/size of shell of the soviet guns over the U.S. gun the model would generate 3 hits in 20 seconds of firing (see example weapons system performance, Chapter with range of 5nm and 8+nm) on the FFG-7, while the FFG-7 inflicted only 1 hit upon the Krivak. Using damage assessment curves we might conclude outcome: FFG-7 out of action - 70% systems degradation. Krivak damaged - 10-15% systems degradation, no change in operations

Considerations:

If LAMPS not airborne, damage potential to FFG-7 much higher. there is a very high potential advantage to unit initiating action due to in contact status of both units.

CASE 4 Harpoon/ 5nm

The existance of harpoon does not change the outcome from CASE III.

Outcome: Same as CASE 3 FFG-7 - out of action; Krivak - continues mission

Discussion

The operation of this example points out two major contributions of this project to the naval ship design process.

It provides a systematic method of providing consistant input to either an existing war gaming model or a model internal to this project. This is an essential element for naval ship design assessment. DEX provides extreme flexibility in this matter.

This project permits the essential communication between the various design levels. In deriving our objective function (combat effectiveness), we have attempted to use the parameters important to each significan discipline involved in the naval ship design process. This should permit the participants to communicate, in common terms, with one another. In short, we have provide a common language (the model) to address the same question (What is the designs' combat effectiveness?).

SITUATION BASELINE

SHIPS

	FFG-7	Krivak II
	Dimensions	
L	135m	23.4m
B	13.7m	14.0m
H	30m	31.0m
	Propulsion	
	41,000shp gas turbine	80,000shp gas turbine
	Speed	
	30kts	32 kts
	Helicopters	
	2 x SH-2 (+) (300kts/100mn)	None

Weapons

Guns

1. 1 x 77mm (86rpm/16km range) 2 x 100mn (?rpm/ ?ra
2. 1 30mm close in weapon

Torpedos

2 x 3 tubes	8 tubes
Missiles	
MK13 standard (AA/anti surface) (10nm/55nm)	SSN -14 (215mn) SAN 4 (8mn)
ASW Weapons	
	2 ASW mortars
Sonar	
SQS-56 (medium frequency)	Hull (Medium/low frequency)
TACTAS (passive array)	Variable depth sonar (Medium frequency)

Electronics

Radar	
Airsearch	
SPS49	HEAD NET "C"
Surface Nav	
SPS 55	DON-2
Fire control (Gun)	

SPG-60 (Missile)

Kitescreech (Guns)

EYE Bowl SSN-14

POP Group SAN-4

Other Forces in Company (from threat/environment section 1A)

none none

Weather

Winds- 10 kts (from north)

Seas - 3-4ft (n)

Visibility - 13nm

Precipitation - none

Jamming - none

EQUIPMENT IN OPERATION/SIGNATURES

FFG-7	Krivak II
Primary Mission	Primary Mission
(AAW Advance Escort)	(ASW Patrol)
Propulsion 16kts (patrol)	12kts (> cavitation speed)
SENSORS	
Sonars	
SQS-56-passive	Hull mounted - passive
Tactas - deployed	Variable depth - active
Active Radars	
49-A radiating/timeshare	Head net C - standby
55 - radiating	Don-2 radiating
Missile/gun radar- standby	Missile/gun radar - standby
ECM	
Auto search (passive)	Search passive

Communications UHF/HF -

EMCON (receive only) UHF/HF-EMCON (Receive only)

(No short range communication techniques (visual horizon) due to single ship operations by both sides.)

Chapter 8

CONCLUSIONS

This project offers "sometime original" by introducting a high level objective function; combat effectiveness; at the feasibility level of the ship design process. It further allows all participants to the process access to the assumptions used to arrive at that objective function.

As discussed in chapter 1, the project team feels that the time is ripe to bring combat effectiveness into the ship design process. Improvements in gaming techniques and modeling have improved the ease of including combat effectiveness within the design process at the preliminary design stage. While it is a fact that there are potential improvements to many other facets of the process to be made by this approach, inclusion of the considerations raised by combat and combat operations should prevent over emphasis or out right suboptimization upon the noncombat considerations. The attributes and potential flexibility of DEX (see chapter 2) are extremely important. The complexity of the ship design process demands maximum integration of the model and the user. It is believed that specification of the means or equipment too early in the process should be avoided. Such premature definition of hardware is a potential disruption

to the total process. In effect it is something done, in many cases, too early and it is the remaining portions of the design which suffer. In effect, when equipment is specified to satisfy a need too early in the process, it may well be that the totality of its impact upon other later design stages may be missed. This model is believed to be a major attempt to include all significant determinants of naval vessel characteristics. Eventually all design processes will, conceivably, be addressed by such a systems approach. The author feels that the techniques exist to permit this effort in the admittedly complex and involved ship design process. All the techniques proposed in this model are in practice, it is the integration of them under a capable software system which is a major contribution of this project.

The impact of weapons/sensor performance upon ship design, is reflected in the sensitivity of the combat effectiveness of the design to them. The combat effectiveness figures and algothrims from chapter 7 are, therefore, a starting point for the ship systems designer. If they represent important, even vital contributions to the effectiveness of a ship in combat, their accuracy is critical. The authors believe that the naval architect/marine enginee· must become actively involved in the determination

and validation of any such techniques used to drive the design process. It is believed that such algorithms are extremely sensitive to minor variations in the system configurations. It will be one essential task of the naval architect/marine engineer of the future to provide the scientific interaction between such causes and their effects. It is this person who might, for example, best model a conceptual weapons effect upon an assumed hull structure to provide a curve such as the damage assessment curve (like figure CE 3).

The framework for a future naval ship design process model has been presented. It will require validation and refinement. The next step in this project will be the development of the modules to support the framework.

REFERENCES

1. Bazilevskiy, S.A., TEORIYA OSHIBOK, (Theory of Errors), Leningrad, Sudostroyeniye,1964.

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8. "Naval Warfare Mission Areas and Required Operational Capability", OpNav Instruction C3501.2E, Department of Defense, 1981.

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APPENDIX

This appendix consists, in order, of the menu all developed menu strings listed below. The numbers refer to the sections defined in figure 1, chapter 1.

Threat/Environment (1a) Surface Threats (pages 1a1-i through 1a1-22)

Non Combat Environment (1b) Command Control and Communication (pages 1b1-i through 1b1-14)

Platform Parameters (3) Signatures (pages 3a-1 through 3b-21)

Platform Parameters (3) Risk Factors (pages 3b-i through 3b-5)

Combat Effectiveness (7) All (pages 7-i through 7-7)

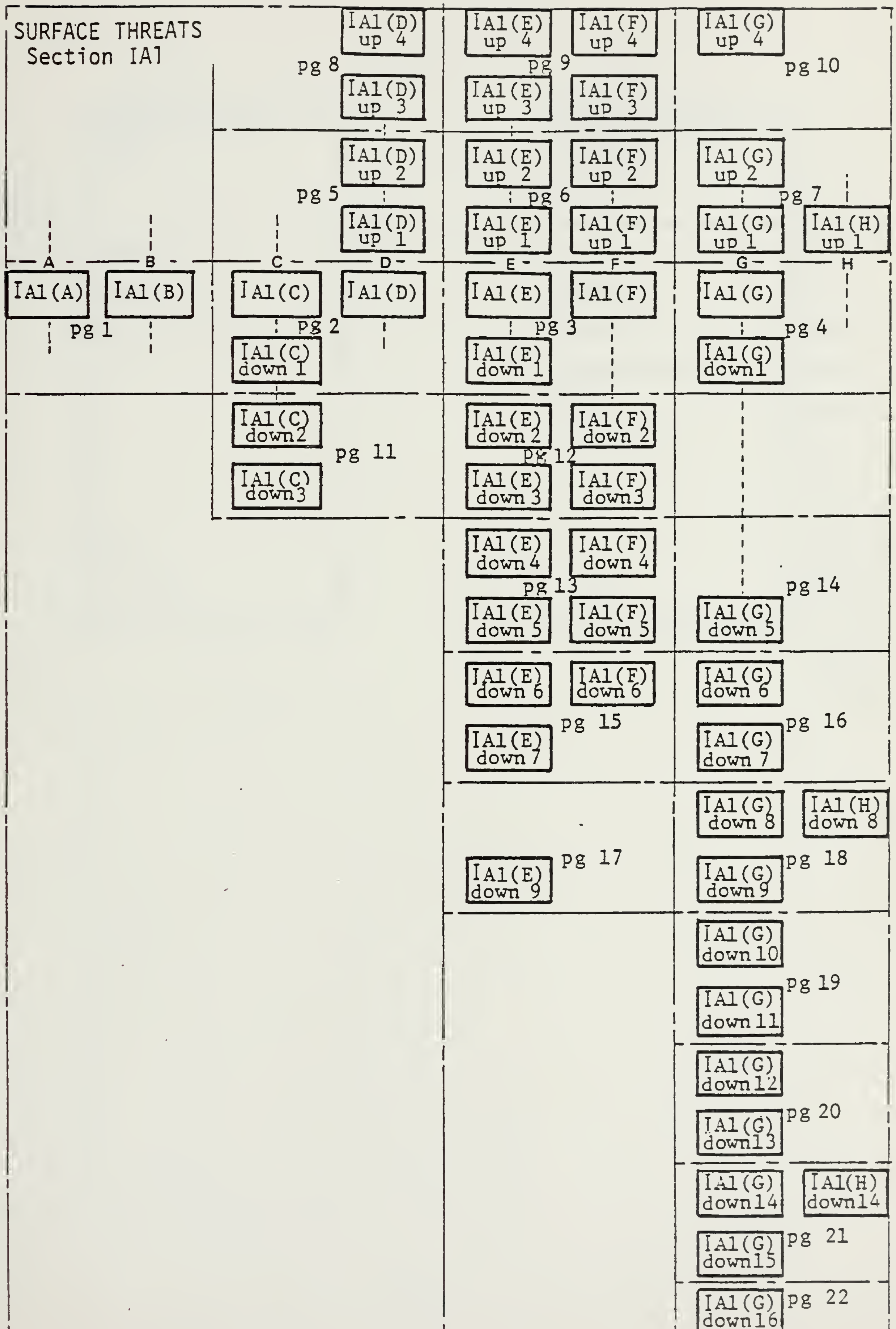
Each menu section consists of a title page, a mapping of the section and pages of 1 to 4 specific menus.

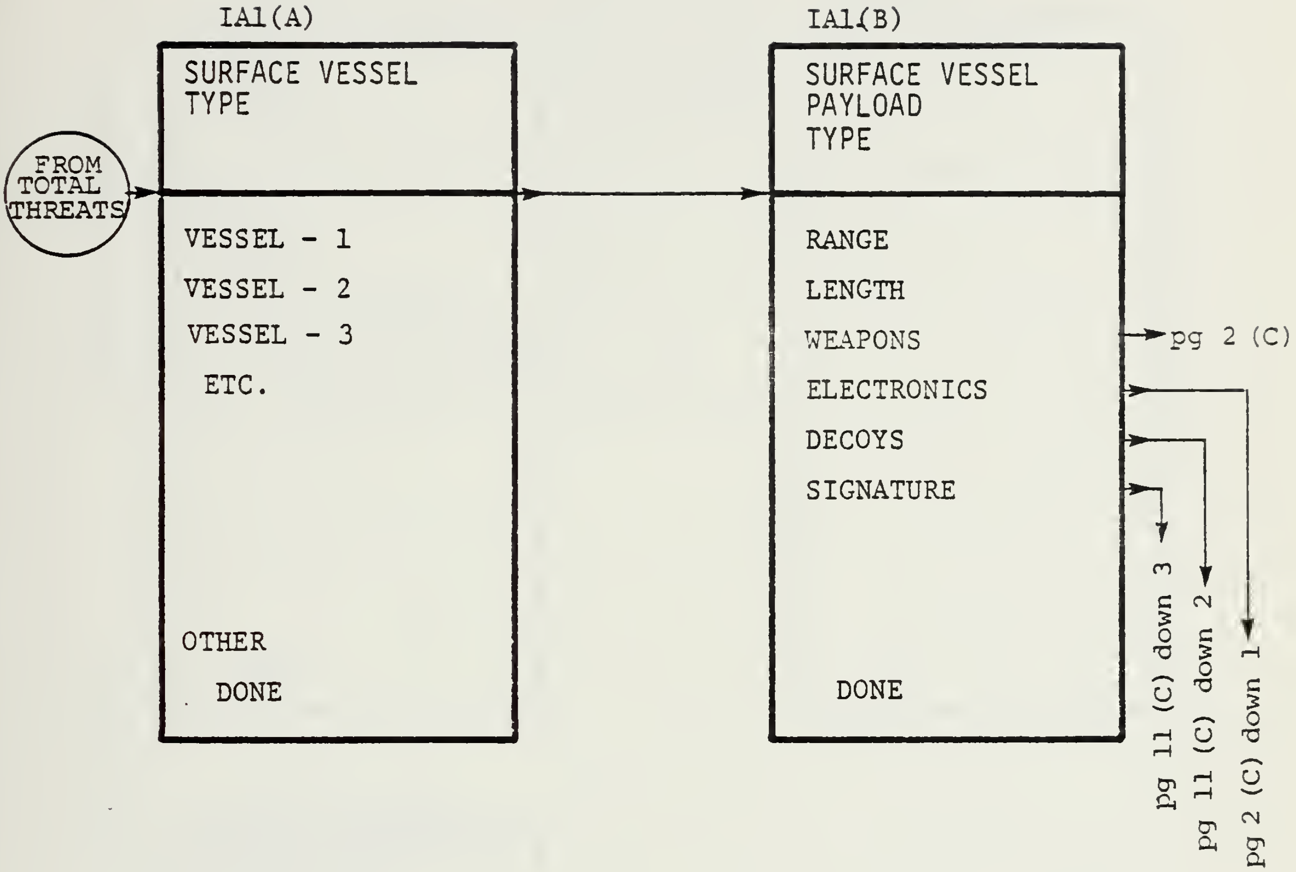
Six menus have been left blank for the application programmer in these ares to insert the appropriate information.

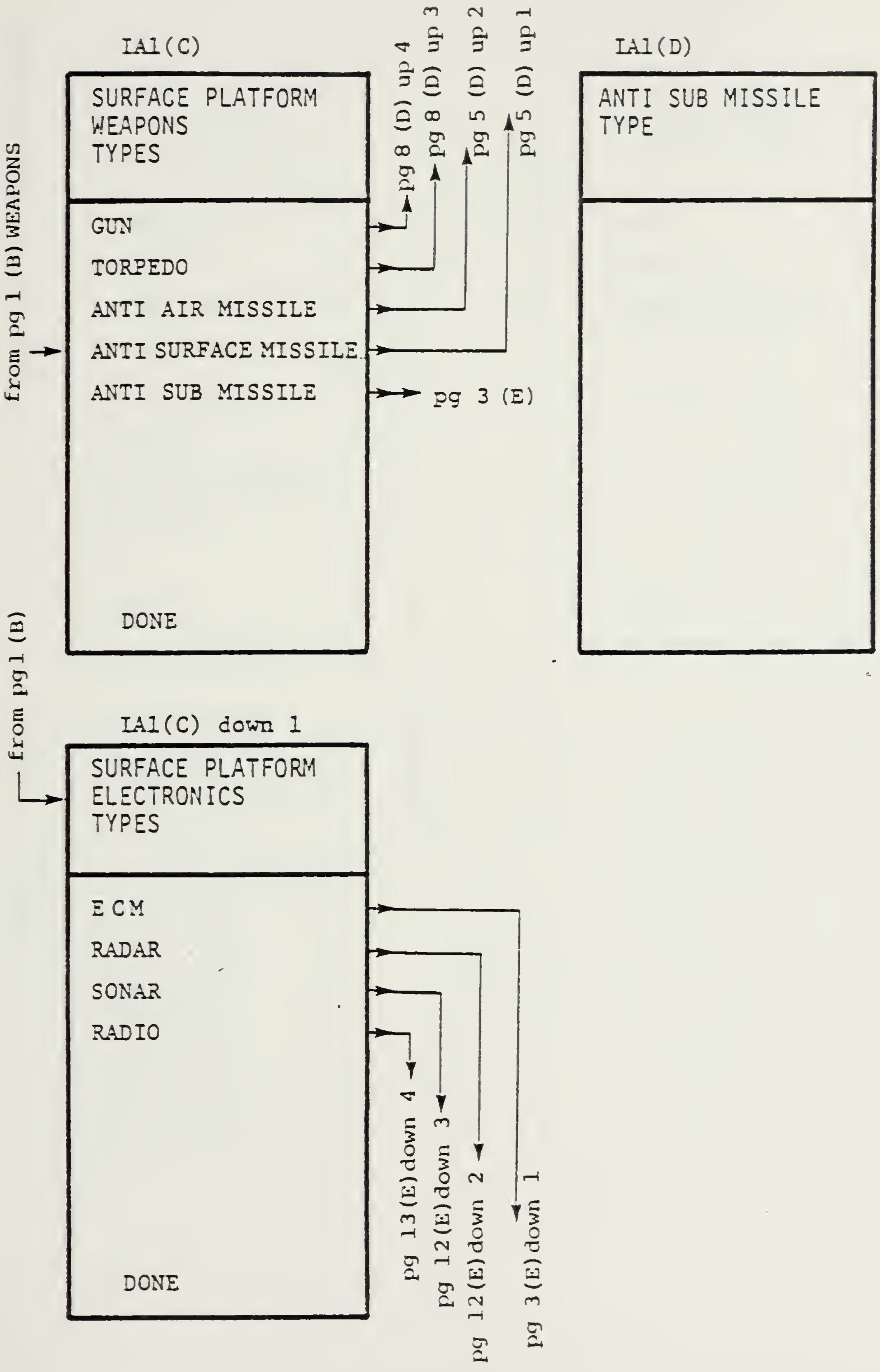
For readability purposes, the eight letter abbreviations required by DEX have not been used in this appendix.

SURFACE THREATS

SECTION IA1


SURFACE THREATS
Section IA1
IA1(A)
IA1(B)
pg 1
IA1(C)
IA1(D)
pg 2
IA1(C) down 1
IA1(E)
IA1(F)
pg 3
IA1(E) down 1
IA1(G)
pg 4
IA1(G) down1
IA1(D) up 1
IA1(D) up 2
pg 5
IA1(E) up 1
IA1(E) up 2
IA1(F) up 1
IA1(F) up 2
pg 6
IA1(G) up 1
IA1(G) up 2
IA1(H) up 1
pg 7
IA1(D) up 3
IA1(D) up 4
pg 8
IA1(E) up 3
IA1(E) up 4
IA1(F) up 3
IA1(F) up 4
pg 9
IA1(G) up 4
pg 10
IA1(C) down2
IA1(C) down3
pg 11
IA1(E) down 2
IA1(E) down 3
IA1(F) down 2
IA1(F) down3
pg 12
IA1(E) down 4
IA1(E) down 5
IA1(F) down 4
IA1(F) down 5
pg 13
IA1(G) down 5
pg 14
IA1(E) down 6
IA1(E) down 7
IA1(F) down 6
pg 15
IA1(G) down 6
IA1(G) down 7
pg 16
IA1(E) down 9
pg 17
IA1(G) down 8
IA1(H) down 8
IA1(G) down 9
pg 18
IA1(G) down 10
IA1(G) down 11
pg 19
IA1(G) down12
IA1(G) down13
pg 20
IA1(G) down14
IA1(H) down14
IA1(G) down15
pg 21
IA1(G) down16
pg 22


IA1(A)
SURFACE VESSEL TYPE
FROM TOTAL THREATS
VESSEL - 1
VESSEL - 2
VESSEL - 3
ETC.
OTHER
DONE
IA1(B)
SURFACE VESSEL PAYLOAD TYPE
RANGE
LENGTH
WEAPONS
ELECTRONICS
DECOYS
SIGNATURE
DONE
pg 2 (C)
pg 11 (C) down 3
pg 11 (C) down 2
pg 2 (C) down 1


IA1(C)
SURFACE PLATFORM WEAPONS TYPES
GUN
TORPEDO
ANTI AIR MISSILE
ANTI SURFACE MISSILE
ANTI SUB MISSILE
DONE
from pg 1 (B) WEAPONS
pg 8 (D) up 4
pg 8 (D) up 3
pg 5 (D) up 2
pg 5 (D) up 1
pg 3 (E)
IA1(D)
ANTI SUB MISSILE TYPE
IA1(C) down 1
from pg 1 (B)
SURFACE PLATFORM ELECTRONICS TYPES
E C M
RADAR
SONAR
RADIO
DONE
pg 13 (E) down 4
pg 12 (E) down 3
pg 12 (E) down 2
pg 3 (E) down 1

IA1(E)

from pg 2 (C) ANTI SUB MISSILE

SURFACE PLATFORM
WEAPONS SPECS.
ANTI SUB MISSILE

WARHEAD
RANGE
FLIGHT SPEED
SIGNATURE
FIRING RATE
GUIDANCE
MAGAZINE CAPACITY
SIGNATURE

DONE

pg 13 (F) down 5

pg 15 (F) down 6

IA1(F)

from pg 6 (E) up 2

SURFACE THREAT
ANTI AIR WEAPON
SIGNATURE TYPE

RADAR
HEAT (I R)
ELECTRO MAGNETIC

DONE

IA1(E) down 1

from pg 2 (C) E C M

SURFACE PLATFORM
ELECTRONICS SPECS.
(E C M)

TYPE
DECOY MODE
POWER LEVEL
FREQUENCY
BAND WIDTH
SENSITIVITY
PULSE WIDTH

DONE

from pg 6 (F) up 1

IA1(G)

SURFACE THREAT
ANTI AIR MISSILE
GUIDANCE SPECS.
(ACTIVE)

ACTIVE POWER

FREQUENCY

PULSE WIDTH

ANTI JAM

DONE

from pg 6 (F) up 1

IA1(G) down 1

SURFACE THREAT
ANTI AIR MISSILE
GUIDANCE SPECS.
(SEMI ACTIVE)

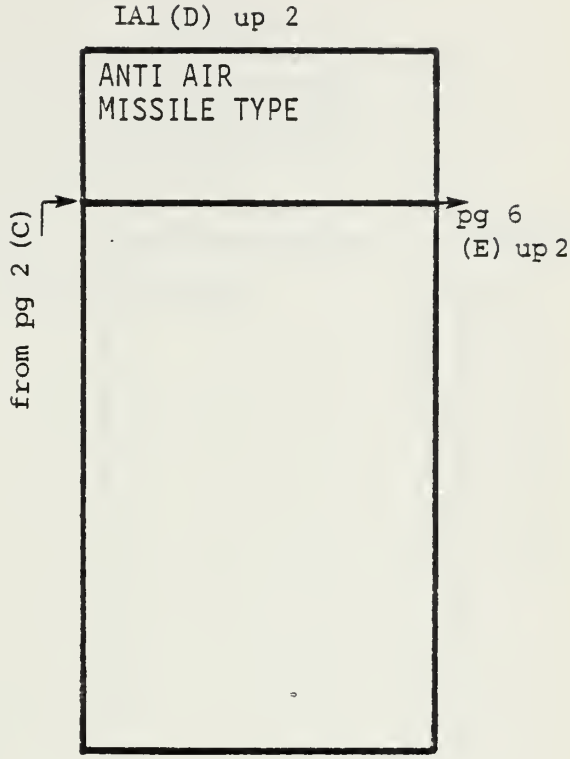
ACTIVE POWER

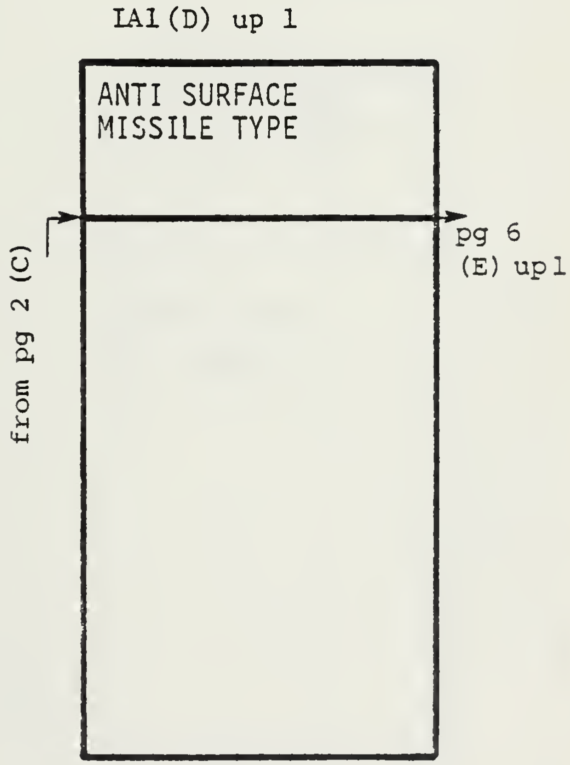
DURATION

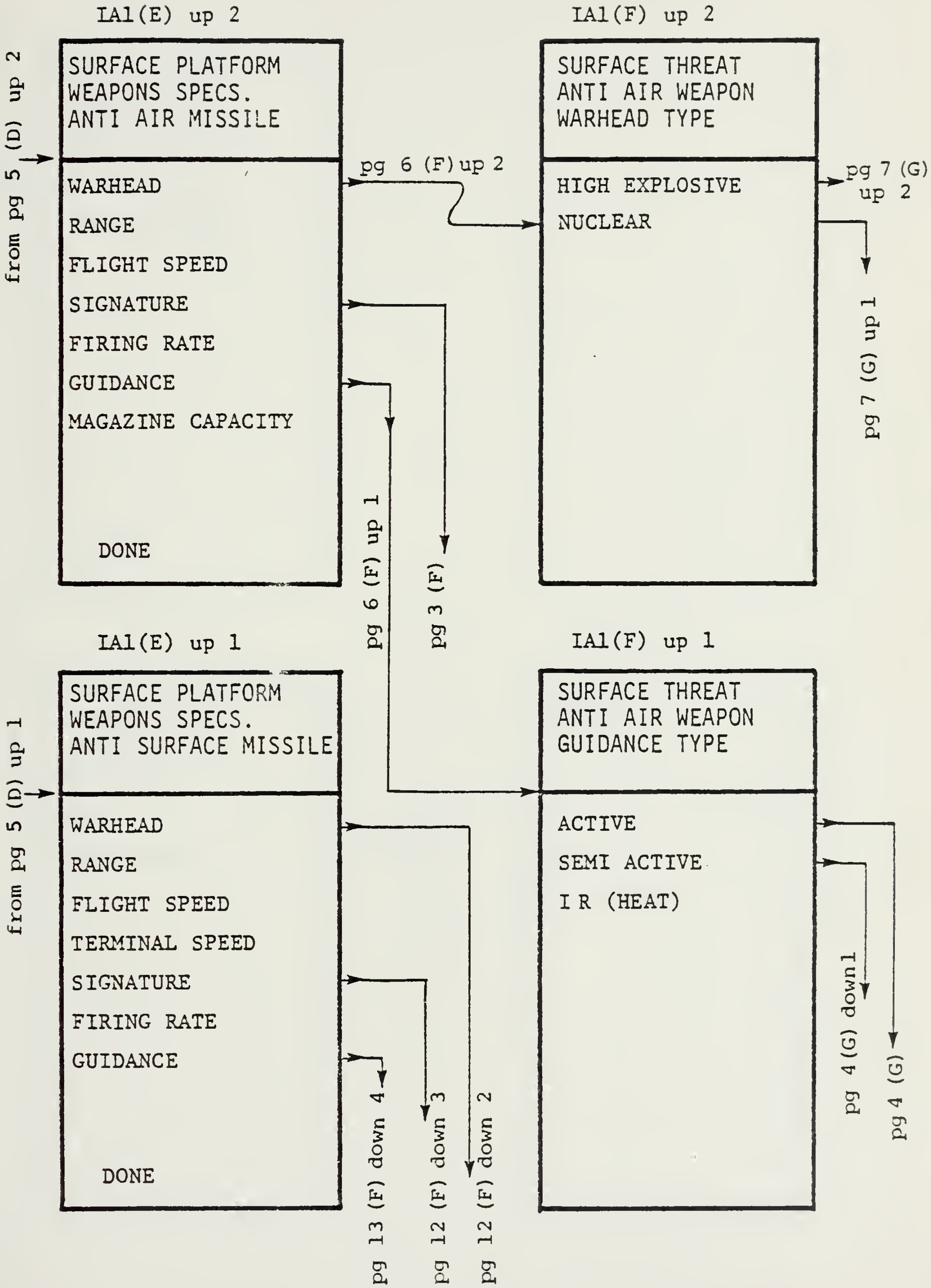
FREQUENCY

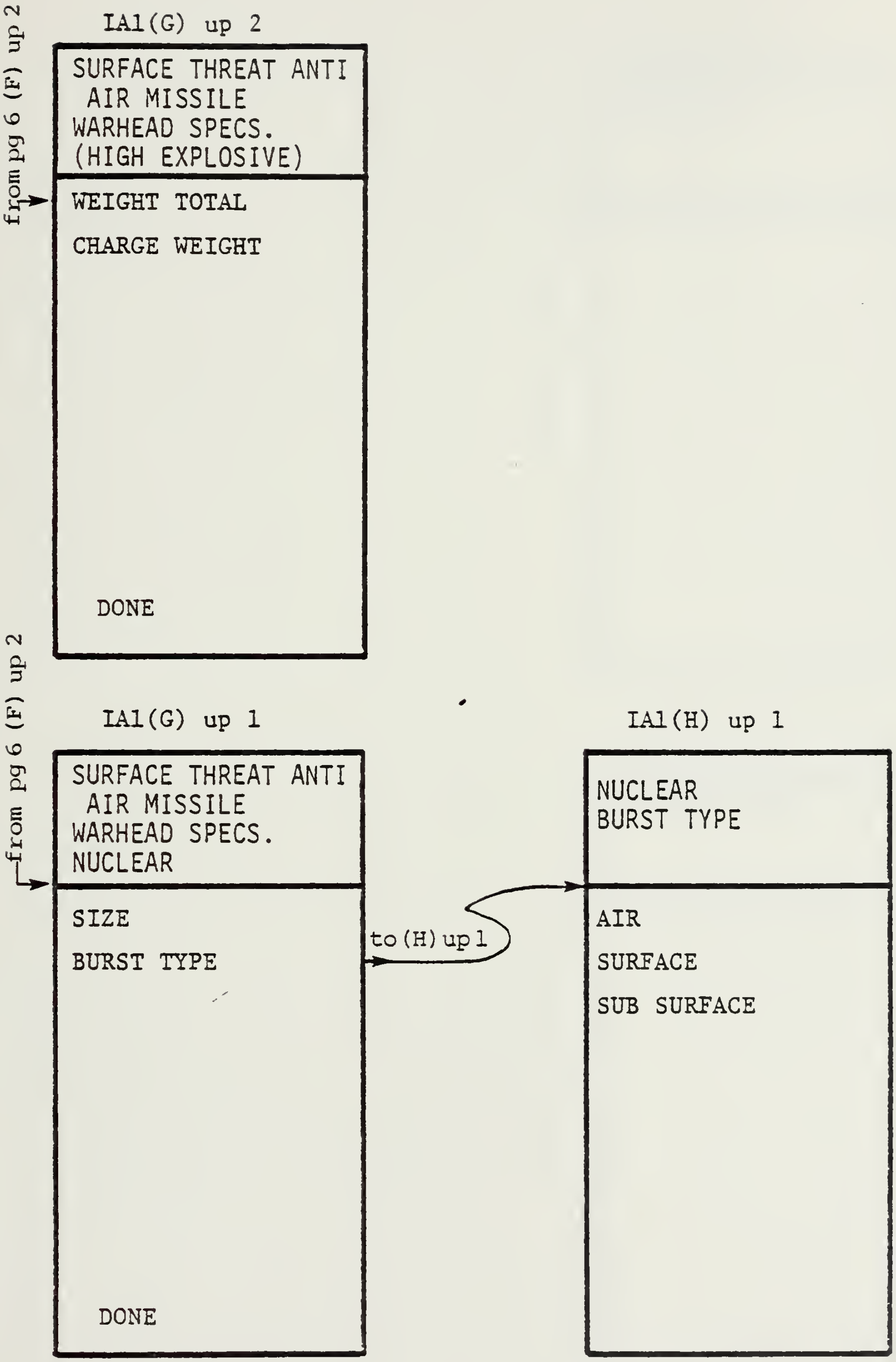
PULSE WIDTH

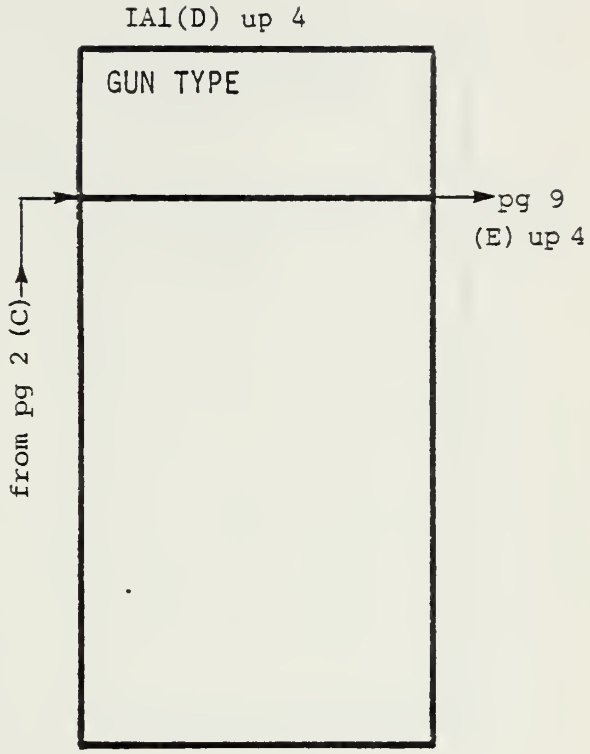
DONE

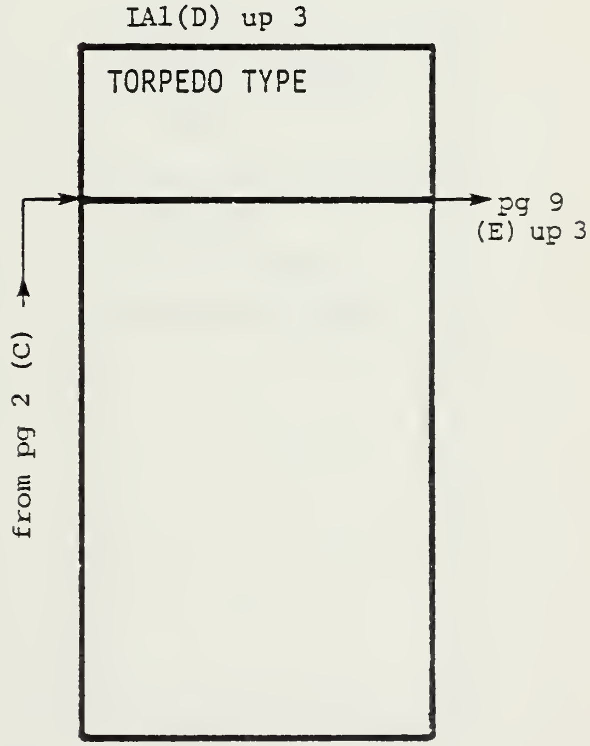

IA1(D) up 2
ANTI AIR
MISSILE TYPE
from pg 2 (C)
pg 6
(E) up 2

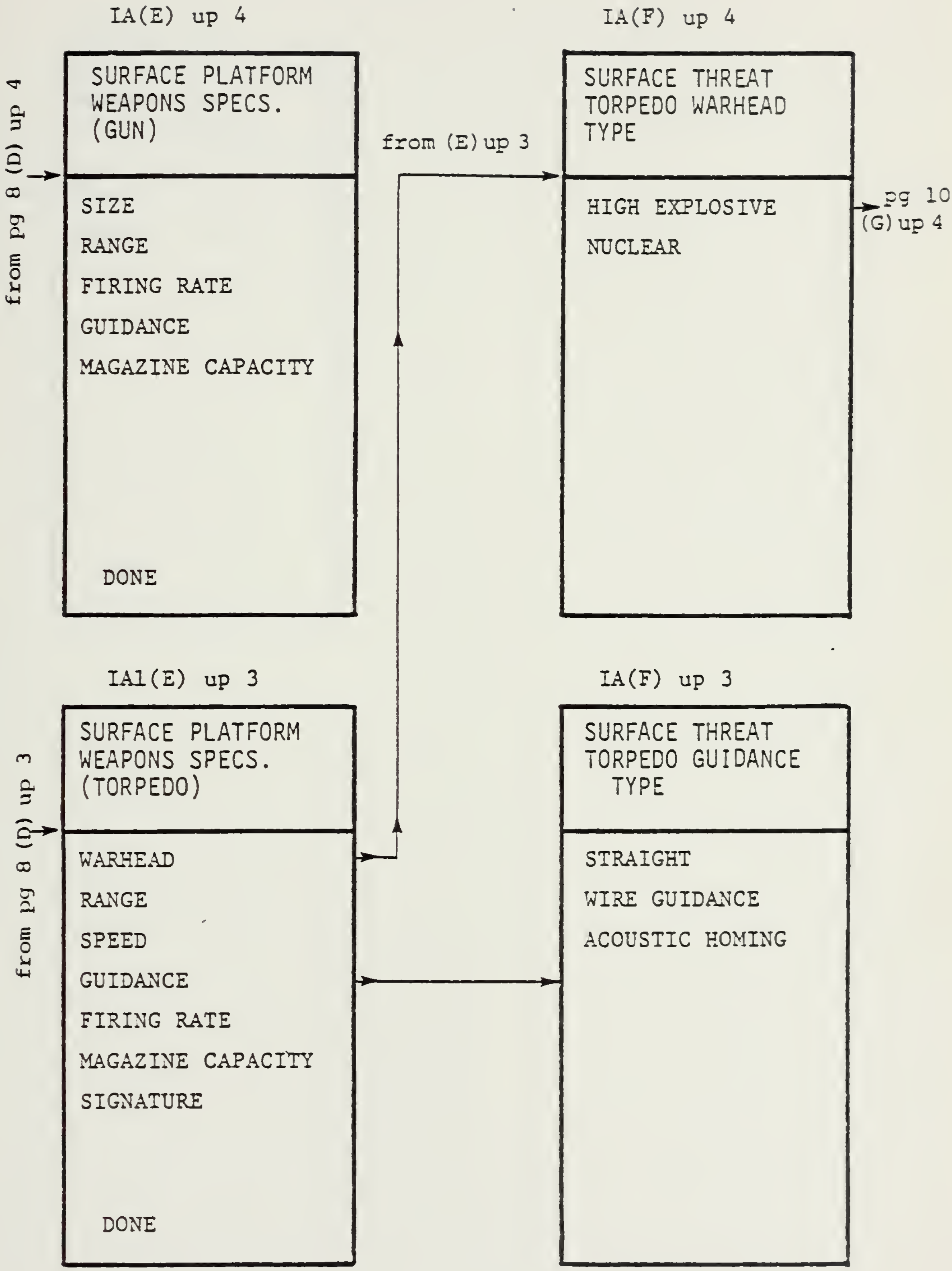

IA1(D) up 1
ANTI SURFACE
MISSILE TYPE
from pg 2 (C)
pg 6
(E) up 1


IA1(E) up 2
SURFACE PLATFORM
WEAPONS SPECS.
ANTI AIR MISSILE
WARHEAD
RANGE
FLIGHT SPEED
SIGNATURE
FIRING RATE
GUIDANCE
MAGAZINE CAPACITY
DONE
from pg 5 (D) up 2
pg 6 (F) up 2
pg 6 (F) up 1
pg 3 (F)
IA1(F) up 2
SURFACE THREAT
ANTI AIR WEAPON
WARHEAD TYPE
HIGH EXPLOSIVE
NUCLEAR
pg 7 (G) up 2
pg 7 (G) up 1
IA1(E) up 1
SURFACE PLATFORM
WEAPONS SPECS.
ANTI SURFACE MISSILE
WARHEAD
RANGE
FLIGHT SPEED
TERMINAL SPEED
SIGNATURE
FIRING RATE
GUIDANCE
DONE
from pg 5 (D) up 1
pg 13 (F) down 4
pg 12 (F) down 3
pg 12 (F) down 2
IA1(F) up 1
SURFACE THREAT
ANTI AIR WEAPON
GUIDANCE TYPE
ACTIVE
SEMI ACTIVE
I R (HEAT)
pg 4 (G) down1
pg 4 (G)


IA1(G) up 2
SURFACE THREAT ANTI AIR MISSILE WARHEAD SPECS. (HIGH EXPLOSIVE)
from pg 6 (F) up 2
WEIGHT TOTAL
CHARGE WEIGHT
DONE
IA1(G) up 1
SURFACE THREAT ANTI AIR MISSILE WARHEAD SPECS. NUCLEAR
from pg 6 (F) up 2
SIZE
BURST TYPE
DONE
to (H) up 1
IA1(H) up 1
NUCLEAR BURST TYPE
AIR
SURFACE
SUB SURFACE


IA1(D) up 4
GUN TYPE
pg 9
(E) up 4
from pg 2 (C)


IA1(D) up 3
TORPEDO TYPE
pg 9
(E) up 3
from pg 2 (C)


IA(E) up 4
from pg 8 (D) up 4
SURFACE PLATFORM WEAPONS SPECS. (GUN)
SIZE
RANGE
FIRING RATE
GUIDANCE
MAGAZINE CAPACITY
DONE
IA(F) up 4
from (E) up 3
SURFACE THREAT TORPEDO WARHEAD TYPE
HIGH EXPLOSIVE
NUCLEAR
pg 10 (G) up 4
IA1(E) up 3
from pg 8 (D) up 3
SURFACE PLATFORM WEAPONS SPECS. (TORPEDO)
WARHEAD
RANGE
SPEED
GUIDANCE
FIRING RATE
MAGAZINE CAPACITY
SIGNATURE
DONE
IA(F) up 3
SURFACE THREAT TORPEDO GUIDANCE TYPE
STRAIGHT
WIRE GUIDANCE
ACOUSTIC HOMING

IA1(G) up 4

from pg 9 (F) up 4

SURF. THREAT TORPEDO
WARHEAD SPECS.
(HIGH EXPLOSIVE)

SIZE

DEPTH

DONE

FROM pg 1(B) DECOYS

IA1(C) down 2

SURFACE VESSEL
DECOY
TYPES

HEAT (I.R.)
ELECTROMAGNETIC
CHAFF

DONE

pg 15 (E) down 7
pg 15 (E) down 6
pg 13 (E) down 5

from pg 1(B) SIGNATURE

IA1(C) down 3

SURFACE VESSEL
SIGNATURE
TYPES

HEAT
ELECTROMAGNETIC
NOISE
WAKE
RADIATION

DONE

pg 17 (E) down 9

from pg 2 (C) down 1 RADAR

IA1(E) down 2

SURFACE PLATFORM ELECTRONICS SPECS. RADAR

- TYPE
- FREQUENCY BAND
- FREQUENCY AGILITY
- POWER OUT
- PLULSE LENGTH
- PULSE WIDTH
- HEIGHT FINDING

DONE

from pg 2 (C) down 1 SONAR

IA1(E) down 3

SURFACE PLATFORM ELECTRONICS SPECS. (SONAR)

- TYPE
- FREQUENCY
- POWER OUT
- FIGURE OF MERIT

DONE

from pg 6 (E) up 1 WARHEAD

IA1(F) down 2

SURFACE THREAT ANTI SURFACE MISSILE WARHEAD TYPE

- HIGH EXPLOSIVE → pg 16 (G) down 6
- SHAPED CHARGE → pg 16 (G) down 7
- NUCLEAR → pg 18 (G) down 8

from pg 6 (E) up 1 SIGNATURE

IA1(F) down 3

SURFACE THREAT ANTI SURFACE MISSILE GUIDANCE TYPE

- ACTIVE RADAR → pg 18 (G) down 9
- SEMI ACTIVE RADAR → pg 19 (G) down 10
- HEAT (I R) → pg 19 (G) down 11

from pg 2 (C) down 1

IA1(E) down 4

SURFACE PLATFORM
ELECTRONICS SPECS.
RADIO

NUMBER
FREQUENCY
POWER OUT
BAND WIDTH

from pg 6 (E) up 1

IA1(F) down 4

SURFACE THREAT
ANTI SURFACE MISSILE
SIGNATURE TYPE

RADAR
HEAT (IR)
ELECTROMAGNETIC

pg 20 (G) down 12

pg 19 (G) down 11

from pg 11 (C) down 2

IA1(E) down 5

SURFACE PLATFORM
DECOY SPECS.
(HEAT)

TYPE
RANGE
FIRING RATE
SIGNATURE

DONE

from pg 3 (E)

IA1(F) down 5

SURFACE THREAT
ANTI SUBMARINE
MISSILE
WARHEAD TYPE

HIGH EXPLOSIVE
NUCLEAR

pg 21 (G) down 14

pg 20 (G) down 13

from pg 3 (F)

IA1(G) down 5

SURFACE THREAT ANTI AIR MISSILE
SIGNATURE SPECS.
(ELECTROMAGNETIC)

POWER

DURATION

FREQUENCY

DONE

from pg 11 (C) down 2

IA1(E) down 6-

SURFACE PLATFORM
DECOY SPECS.
(ELECTROMAGNETIC)

TYPE

FREQUENCY

POWER

RANGE

FIRING RATE

SIGNATURE

DONE

from pg 3 (E)

IA1(F) down 6

SURFACE THREAT
ANTI SUBMARINE
MISSILE
SIGNATURE TYPE

RADAR

HEAT (IR)

ELECTROMAGNETIC

pg 22 (G) down 16

from pg 11 (C) down 2

IA1(E) down 7

SURFACE PLATFORM
DECOY SPECS.
CHAFF

TYPE (AMT. RIBBONS)

FREQUENCY

SIZE RIBBONS

RANGE

FIRING RATE

SIGNATURE

DONE

from pg 12 (F) down 2

IA1(G) down 6

SURFACE THREAT
ANTI SURFACE MISSILE
WARHEAD SPECS.
(HIGH EXPLOSIVE)

WEIGHT TOTAL

WEIGHT CHARGE

DONE

from pg 12 (F) down 2

IA1(G) down 7

SURFACE THREAT
ANTI SURFACE MISSILE
WARHEAD SPECS.
(SHAPED CHARGE)

SIZE

STAND OFF

DONE

IA1(E) down 9

from pg 11 (C) down 3

SURFACE PLATFORM
SIGNATURE SPECS.
(NOISE)

NUMBER

FREQUENCY

SIGNAL STRENGTH

DONE

from pg 12 (F) down 2

IA1(G) down 8

SURFACE THREAT ANTI
SURFACE MISSILE
WARHEAD SPECS.
(NUCLEAR)

SIZE

BURST TYPE

DONE

IA1(H) down 8

NUCLEAR
BLAST
TYPE

from (G)
down 8

AIR

SURFACE

SUB SURFACE

from pg 12 (F) down 3

IA1(G) down 9

SURFACE THREAT ANTI
SURFACE MISSILE
GUIDANCE SPECS.
ACTIVE RADAR

POWER OUT

PULSE WIDTH

FREQUENCY

ANTI JAM

DONE

from pg 12 (F) down 3

IA1(G) down 10

SURFACE THREAT ANTI
SURFACE MISSILE
GUIDANCE SPECS.
SEMI ACTIVE RADAR

ACTIVE POWER

DURATION

FREQUENCY

PULSE WIDTH

DONE

from pg 13 (F) down 3

IA1(G) down 11

SURFACE THREAT ANTI
SURFACE MISSILE
SIGNATURE SPECS.
HEAT (I R)

AMOUNT (TERMINAL)

AMOUNT (FLIGHT)

DONE

from pg 13 (F) down 4

IA1(G) down 12

SURFACE THREAT ANTI SURFACE MISSILE SIGNATURE SPECS. (ELECTROMAGNETIC)
POWER DURATION FREQUENCY DONE

from pg 13 (F) down 5

IA1(G) down 13

SURFACE THREAT ANTI SUB. MISSILE WARHEAD SPECS (HIGH EXPLOSIVE)
WEIGHT TOTAL WEIGHT CHARGE DONE

from pg 13 (F) down 5

IA1(G) down 14

SURFACE THREAT ANTI SUBMARINE MISSILE WARHEAD SPECS. (NUCLEAR)

SIZE

BURST TYPE

DONE

from (G) down 14

IA1(H) down 14

NUCLEAR BURST TYPE

SURFACE

AIR

SUB SURFACE

from pg 15 (F) down 6

IA1(G) down 15

SURFACE THREAT ANTI SUBMARINE MISSILE SIGNATURE SPECS. (HEAT (I R)

AMOUNT (TERMINAL)

AMOUNT (FLIGHT)

DONE

from pg 15 (F) down 6
ELECTROMAGNETIC

IA1(G) down 16

SURFACE THREAT
ANTI-SUB. MISSILE
SIGNATURE SPECS.
ELECTRO MAGNETIC

POWER

DURATION

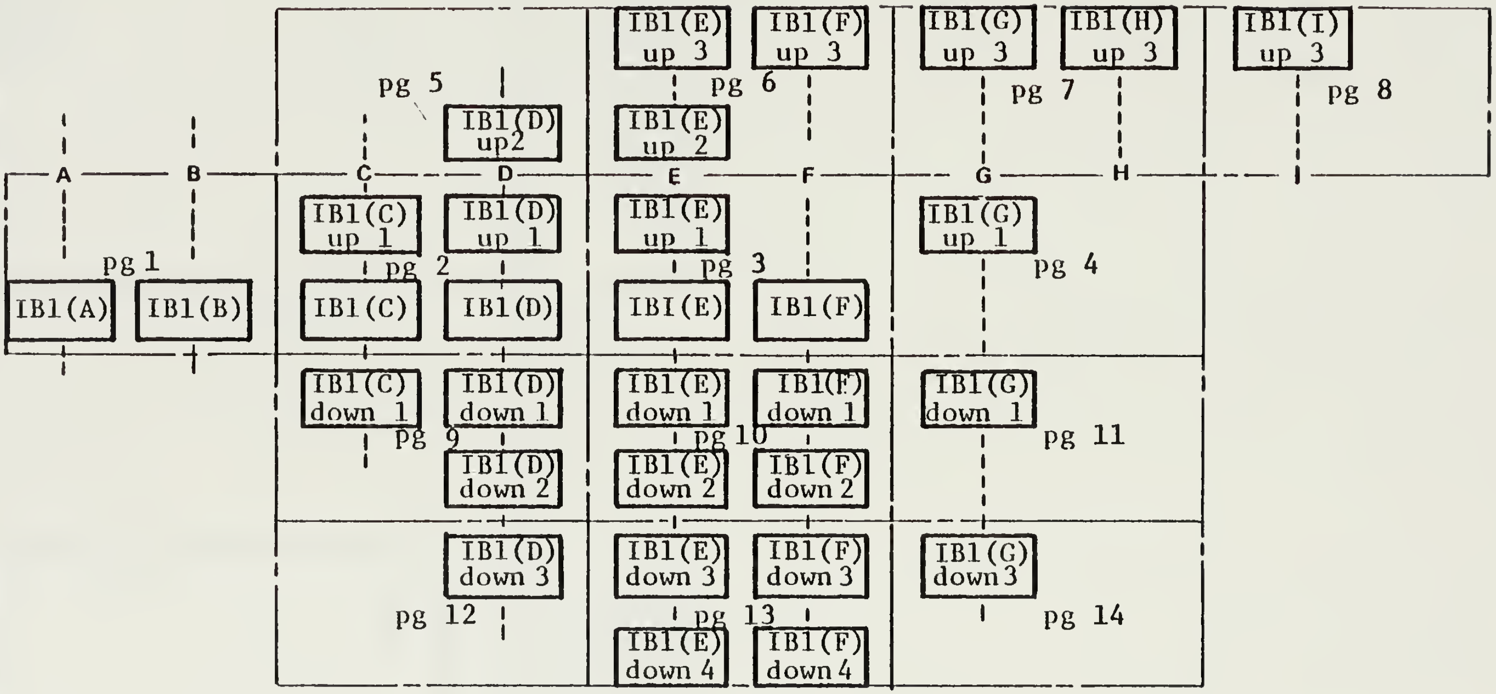
FREQUENCY

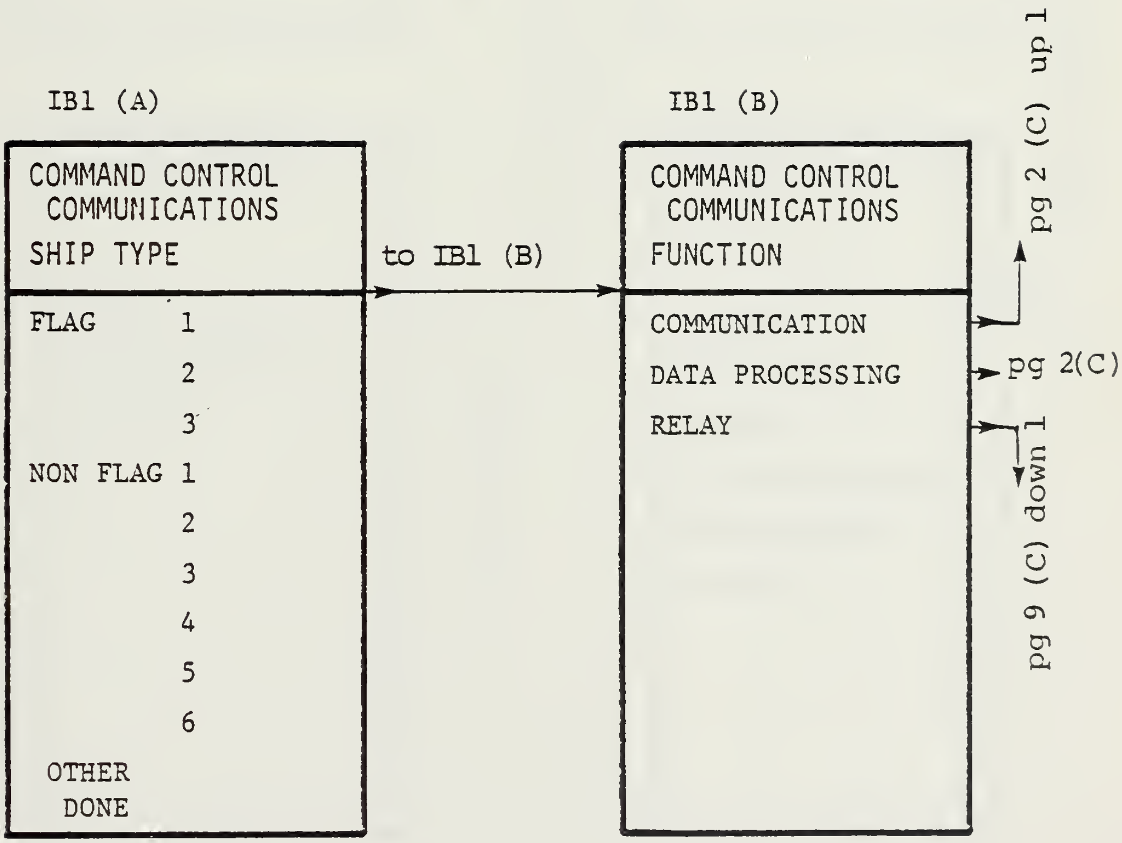
DONE

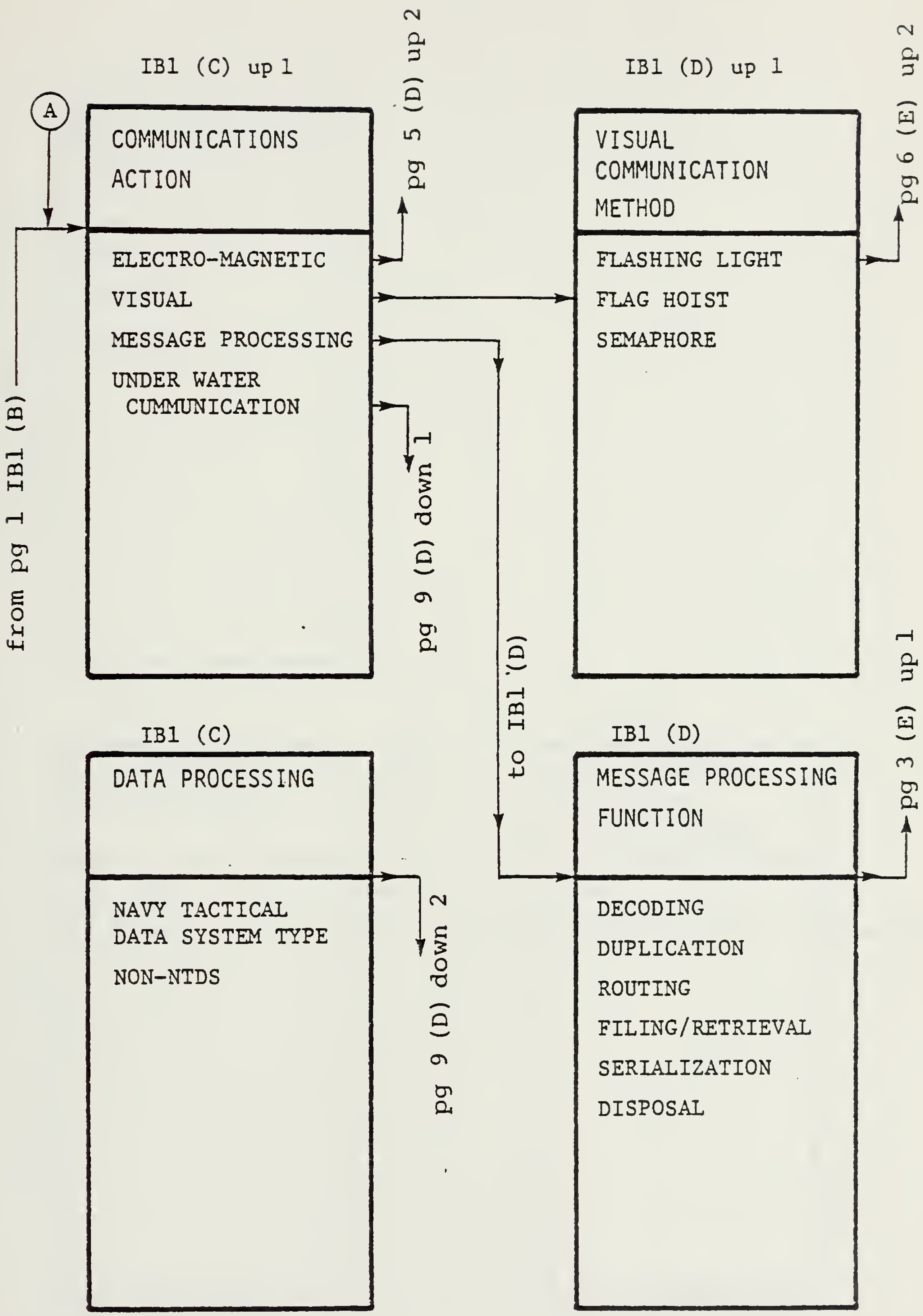
COMMAND CONTROL AND
COMMUNICATIONS MENUS

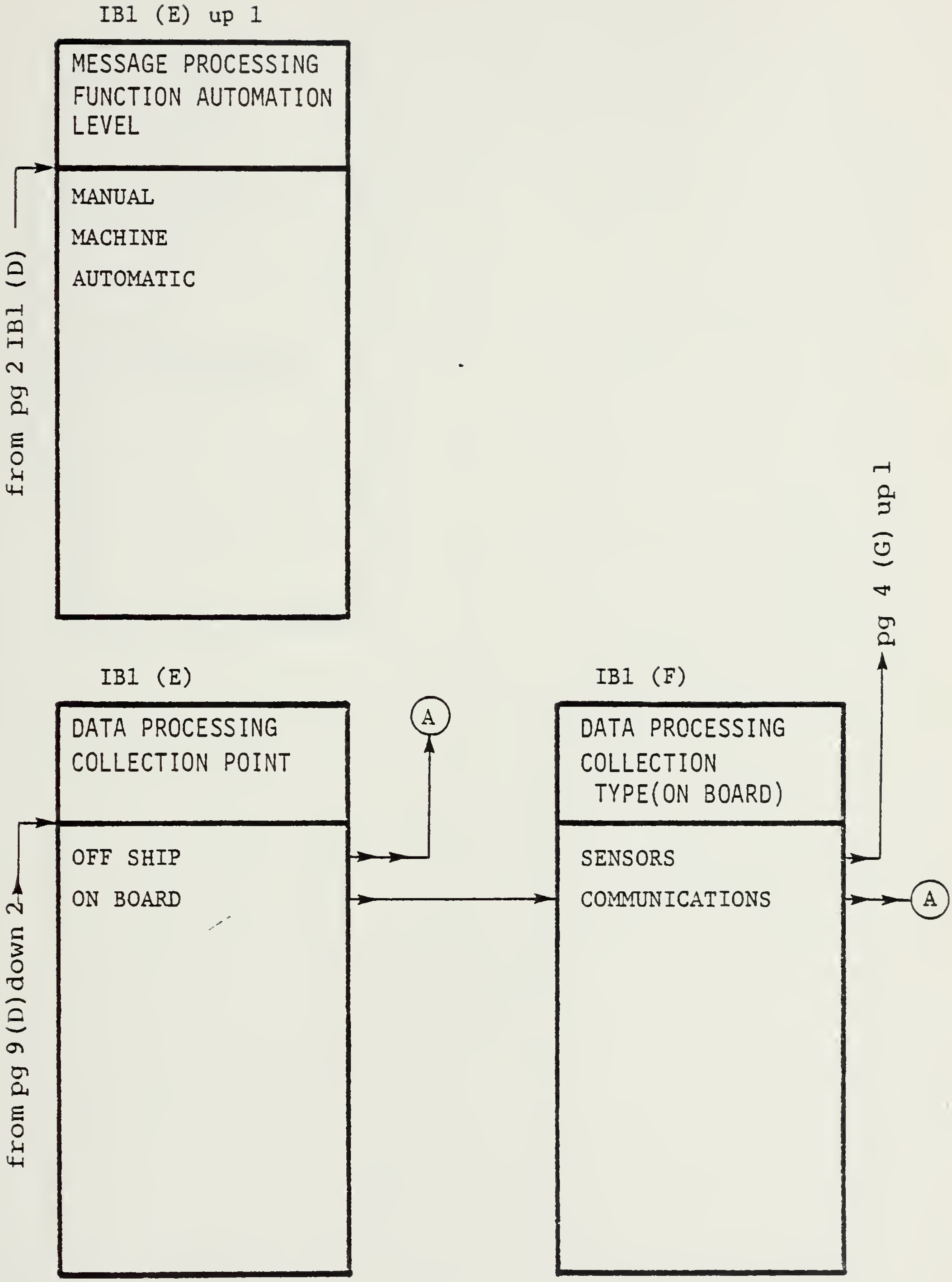
(REF. OPNAV 3501.1E)
SECTION IB1

COMMAND CONTROL AND COMMUNICATIONS MENUS
(REF. OPNAV 3501.1E)
Section IB1




IB1 (A)
COMMAND CONTROL
COMMUNICATIONS
SHIP TYPE
FLAG 1
2
3
NON FLAG 1
2
3
4
5
6
OTHER
DONE
to IB1 (B)
IB1 (B)
COMMAND CONTROL
COMMUNICATIONS
FUNCTION
COMMUNICATION
DATA PROCESSING
RELAY
pg 2 (C) up 1
pg 2(C)
pg 9 (C) down 1


IB1 (C) up 1
COMMUNICATIONS ACTION
ELECTRO-MAGNETIC
VISUAL
MESSAGE PROCESSING
UNDER WATER CUMMUNICATION
pg 5 (D) up 2
pg 9 (D) down 1
from pg 1 IB1 (B)
A
IB1 (D) up 1
VISUAL COMMUNICATION METHOD
FLASHING LIGHT
FLAG HOIST
SEMAPHORE
pg 6 (E) up 2
to IB1 (D)
IB1 (C)
DATA PROCESSING
NAVY TACTICAL DATA SYSTEM TYPE
NON-NTDS
pg 9 (D) down 2
IB1 (D)
MESSAGE PROCESSING FUNCTION
DECODING
DUPLICATION
ROUTING
FILING/RETRIEVAL
SERIALIZATION
DISPOSAL
pg 3 (E) up 1


IB1 (E) up 1
MESSAGE PROCESSING FUNCTION AUTOMATION LEVEL
MANUAL
MACHINE
AUTOMATIC
from pg 2 IB1 (D)
IB1 (E)
DATA PROCESSING COLLECTION POINT
OFF SHIP
ON BOARD
A
from pg 9 (D) down 2
IB1 (F)
DATA PROCESSING COLLECTION TYPE(ON BOARD)
SENSORS
COMMUNICATIONS
A
pg 4 (G) up 1

IB1 (G) up 1

DATA PROCESSING
COLLECTION
SENSOR TYPE

from pg 3 IB1(F)

VISUAL/OPTICS
HEAT/I R
RADAR
SONAR
ELECTRO MAGNETIC

IB1 (D) up 2

from pg 2 (C) up 1

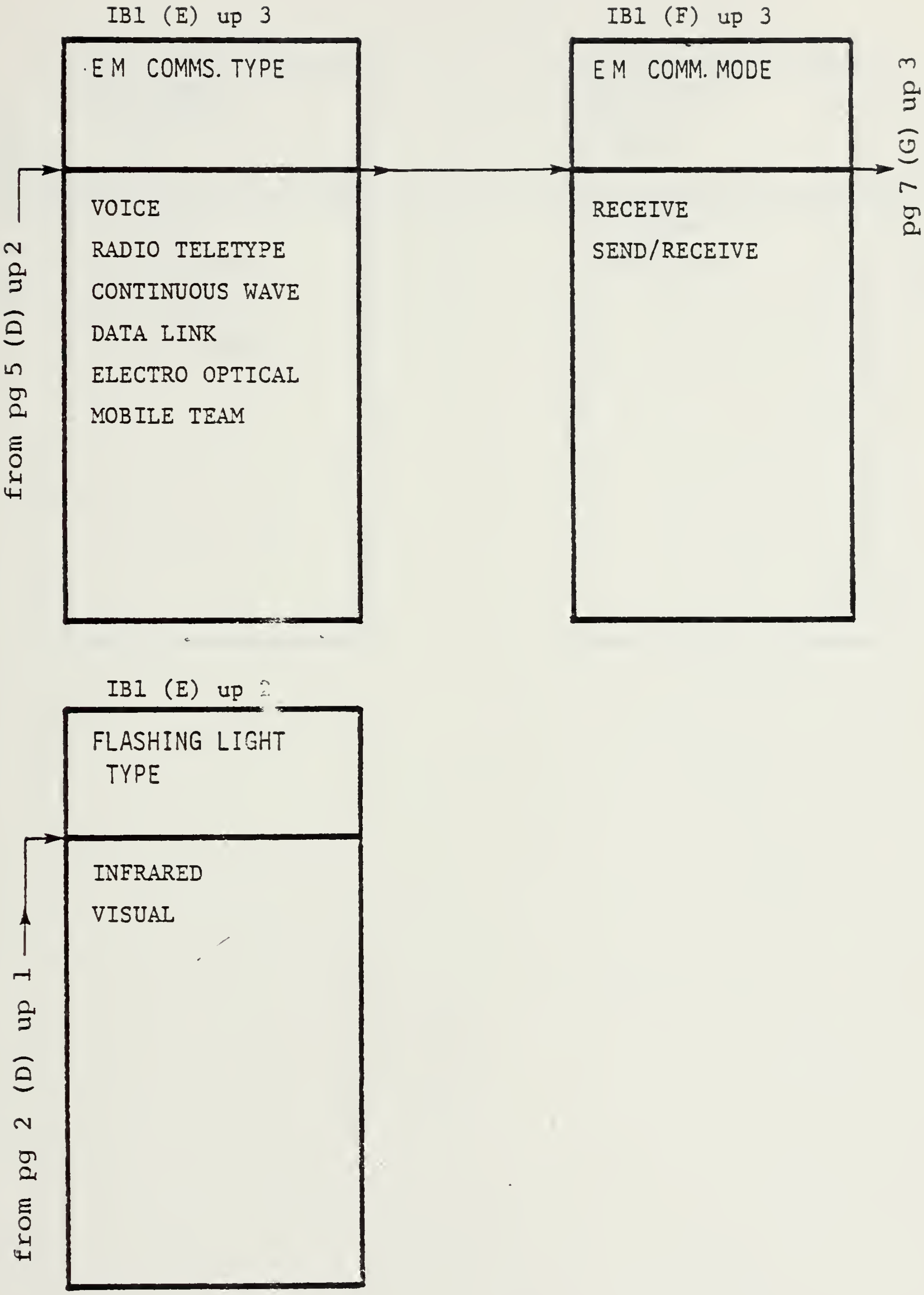
ELECTRO MAGNETIC (EM)
COMMUNICATION
METHOD

SATELLITE

NON SATELLITE

HELO

pg 6 (E) up 3


IB1 (E) up 3
EM COMMS. TYPE
VOICE
RADIO TELETYPE
CONTINUOUS WAVE
DATA LINK
ELECTRO OPTICAL
MOBILE TEAM
from pg 5 (D) up 2
IB1 (F) up 3
EM COMM. MODE
RECEIVE
SEND/RECEIVE
pg 7 (G) up 3
IB1 (E) up 2
FLASHING LIGHT TYPE
INFRARED
VISUAL
from pg 2 (D) up 1

pg 6 (F) up 3

IB1 (G) up 3

EM COMMS TERMINATION TYPE
SIMPLEX
HALF DUPLEX
FULL DUPLEX
MULTI CHANNEL

IB1 (H) up 3

EM COMMS RANGE TYPE
TACTICAL
STRATEGIC

pg 8 (I) up 3

IB1 (I) up 3

from pg 7 (H) up 3

EM COMMS
SECURITY

SECURE
NON SECURE

IB1 (C) down 1

pg 1 (B)

RELAY FREQUENCY TYPE
VISUAL
ACOUSTIC
ELECTROMAGNETIC
ELECTRO OPTICAL

pg 12 (D) down 3

IB1 (D) down 1

pg 2 (C) up 1

UNDER WATER COMMUNICATIONS TYPE
EXPLOSION
ULTRA LOW FREQUENCY
VOICE

IB1 (D) down 2

pg 2 (C)

DATA PROCESSING FUNCTION
COLLECT
PROCESS
DISPLAY
DECISION

IB1 (E) down 1

DATA PROCESSING
PROCESSING TYPE

AUTOMATIC
MANUAL

pg 9 (D) down 2

IB1 (F) down 1

DATA PROCESSING
POINT

OFF SHIP
ON BOARD

pg 11 (G) down 1

A

IB1 (E) down 2

DATA PROCESSING
DISPLAY GENERATION MODE

MANUAL
MACHINE
AUTOMATIC

pg 9 (D) down 2

IB1 (F) down 2

DATA PROCESSING
DISPLAY TYPE

AREA
PERSONAL

IB1 (G) down 1

DATA PROCESSING

COMMUNICATION
(LOCATION)

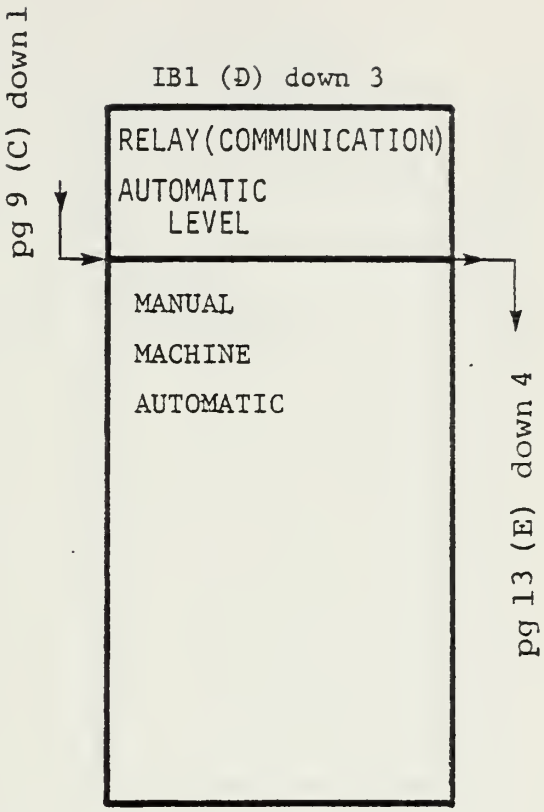
pg 10 (F) down 1

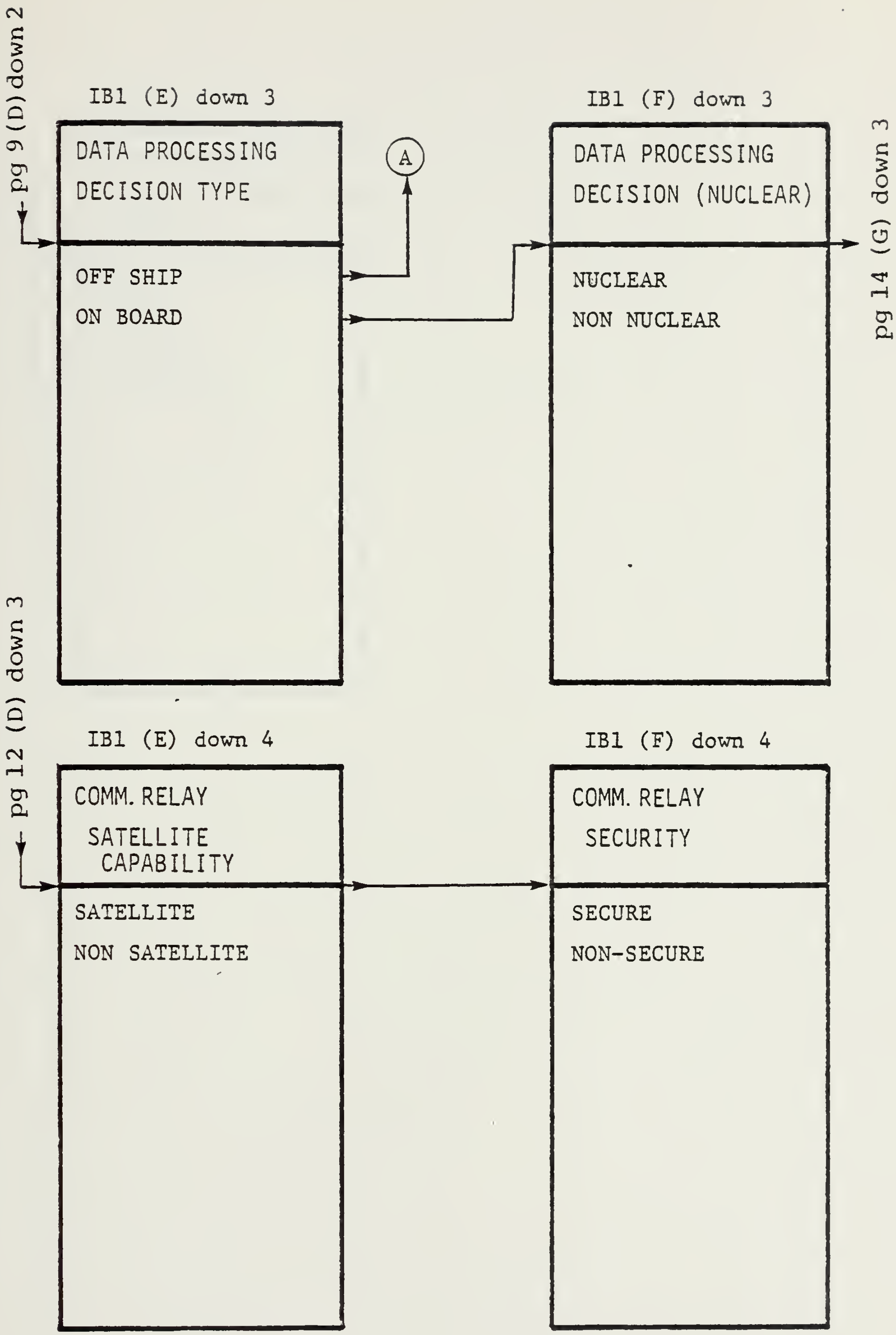
DATA PROCESS CENTER

DISTRIBUTED SYSTEM

C I C

CONSOLE


IB1 (D) down 3
RELAY(COMMUNICATION)
AUTOMATIC
LEVEL
MANUAL
MACHINE
AUTOMATIC
pg 9 (C) down 1
pg 13 (E) down 4


pg 9 (D) down 2
IB1 (E) down 3
DATA PROCESSING DECISION TYPE
OFF SHIP
ON BOARD
A
IB1 (F) down 3
DATA PROCESSING DECISION (NUCLEAR)
NUCLEAR
NON NUCLEAR
pg 14 (G) down 3
pg 12 (D) down 3
IB1 (E) down 4
COMM. RELAY SATELLITE CAPABILITY
SATELLITE
NON SATELLITE
IB1 (F) down 4
COMM. RELAY SECURITY
SECURE
NON-SECURE

IB1 (G) down 3

from pg 13 (F) down 3

DATA PROCESSING DECISION AUTOMATION LEVEL

MANUAL

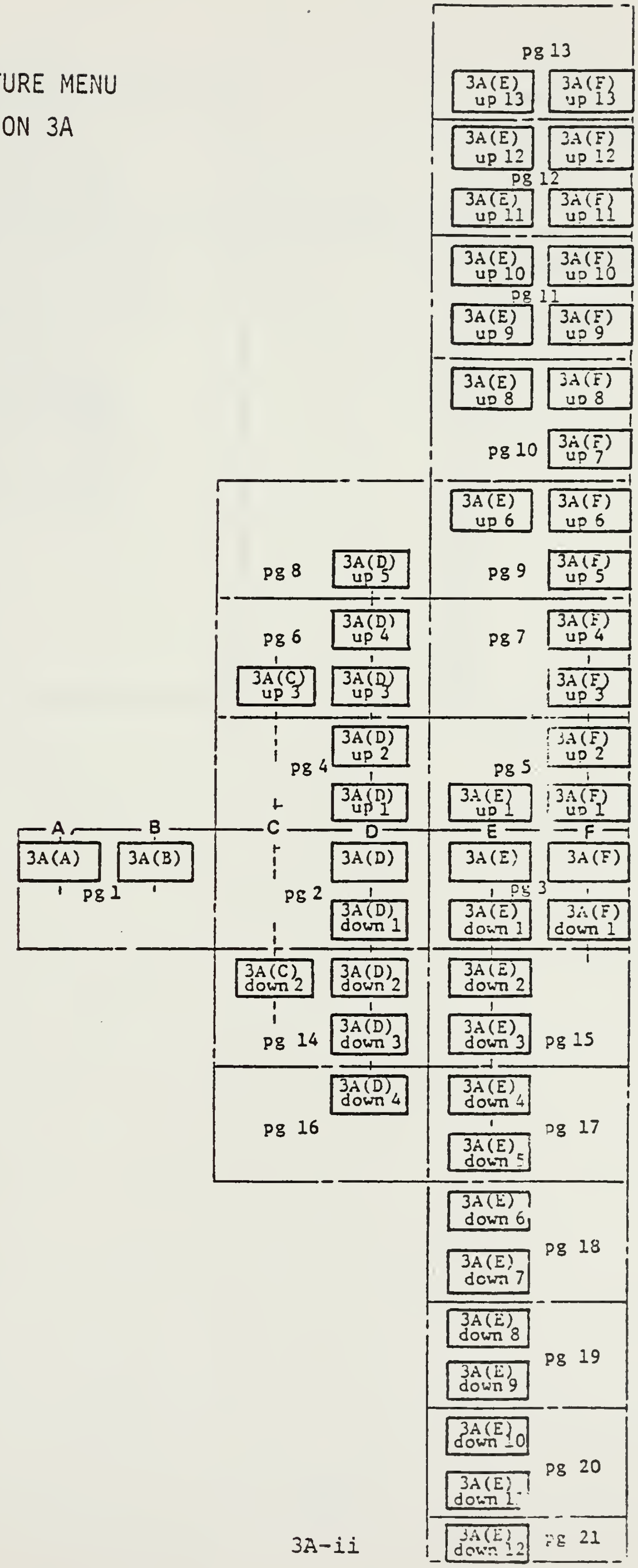
MACHINE

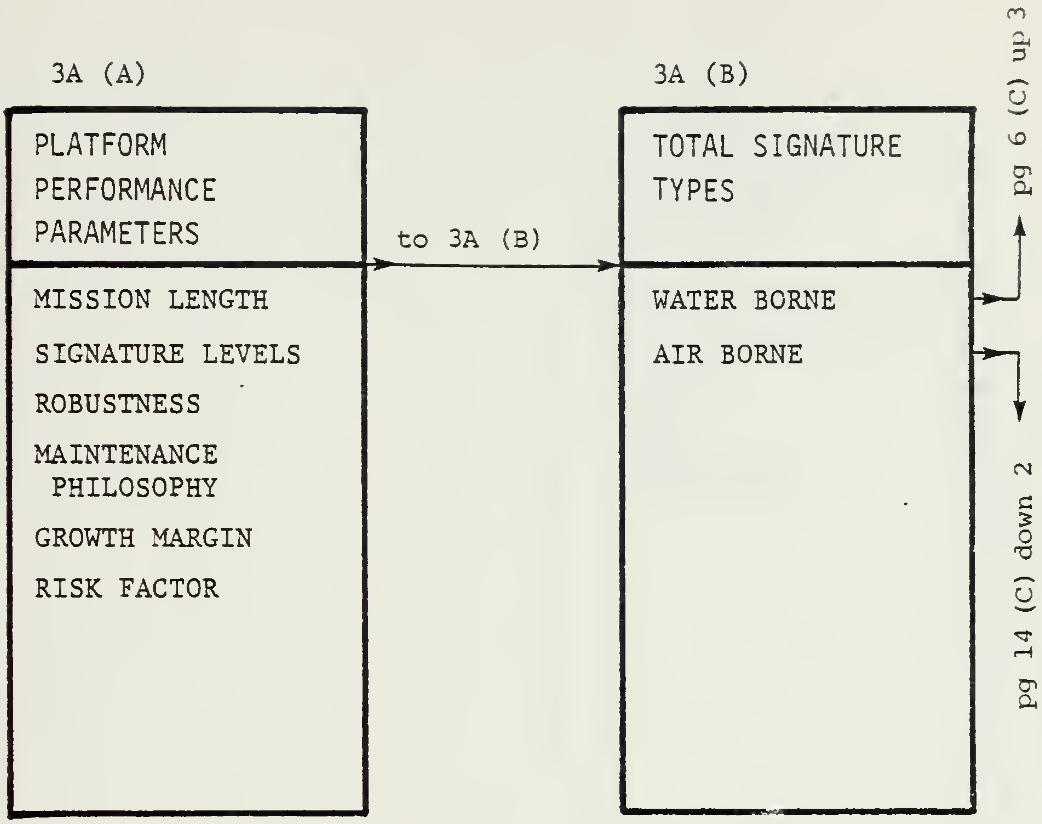
AUTOMATIC

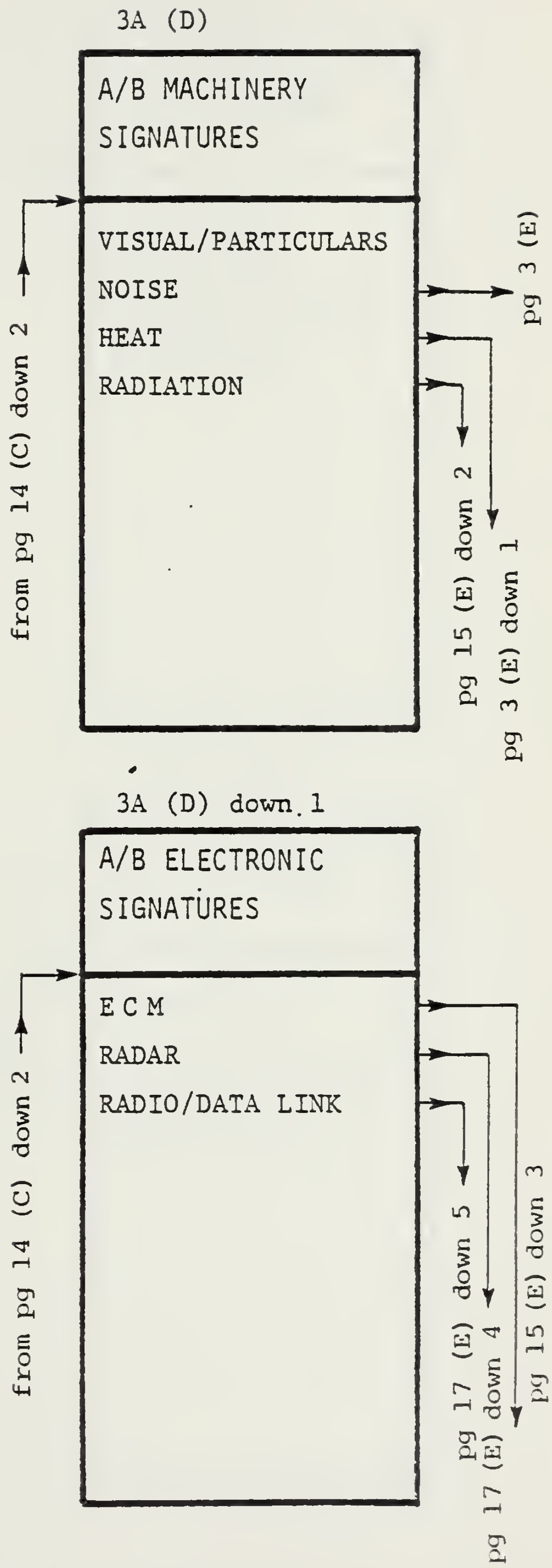
SIGNATURE MENU
SECTION 3A

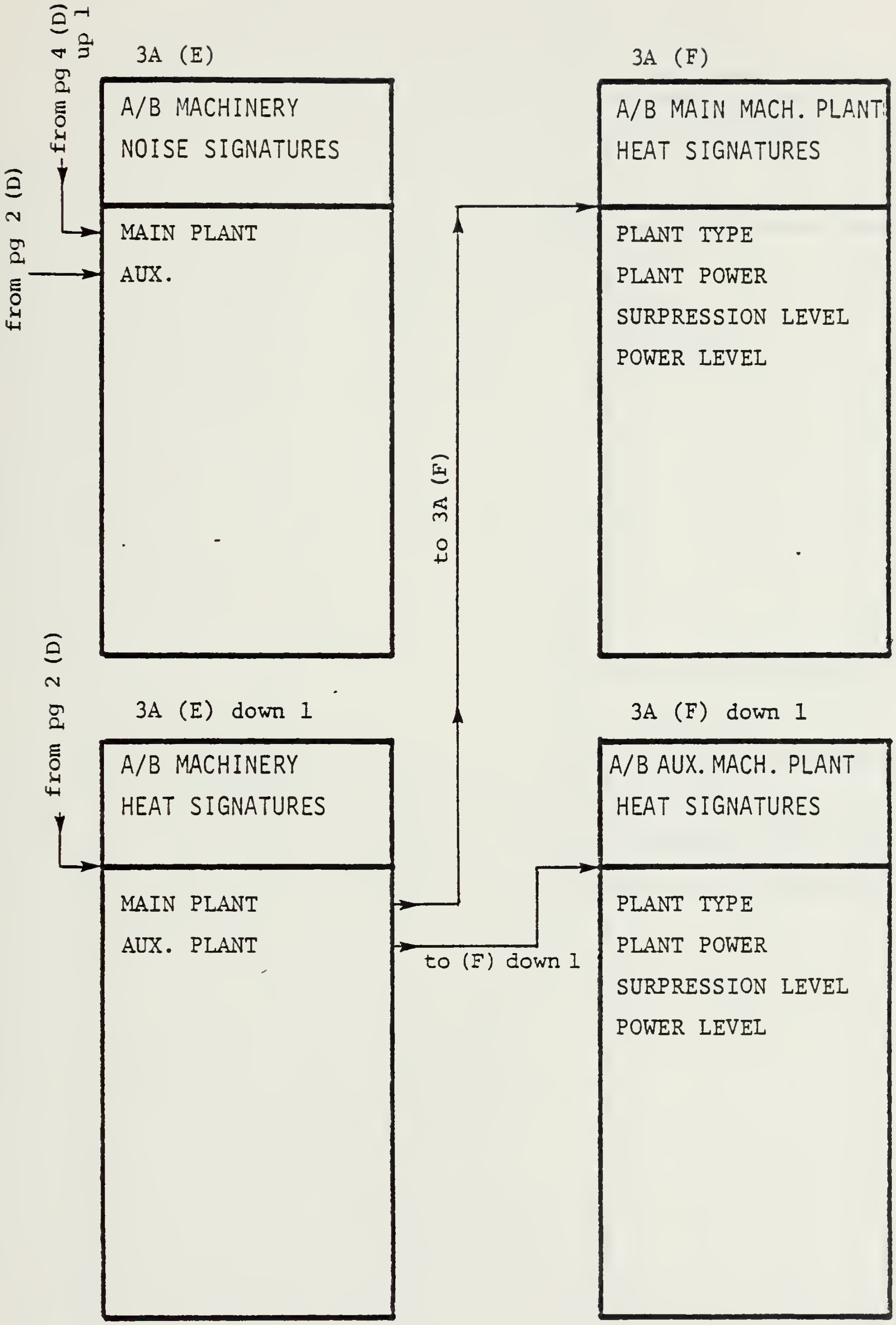
SIGNATURE MENU

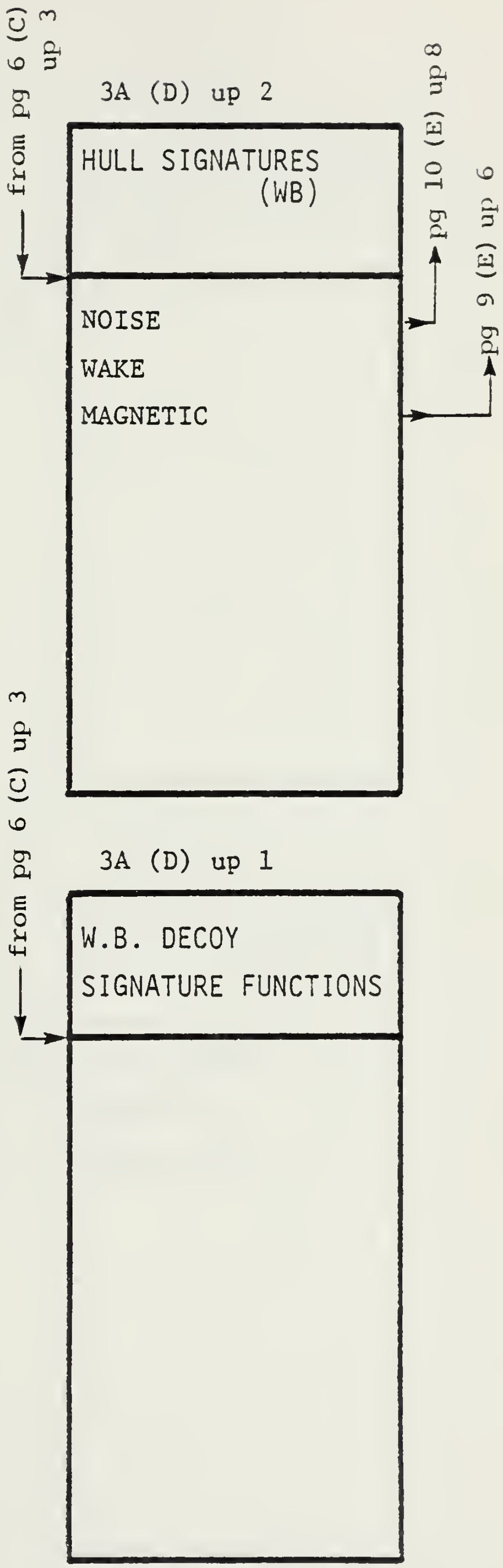
SECTION 3A




3A (A)
PLATFORM PERFORMANCE PARAMETERS
MISSION LENGTH
SIGNATURE LEVELS
ROBUSTNESS
MAINTENANCE PHILOSOPHY
GROWTH MARGIN
RISK FACTOR
to 3A (B)
3A (B)
TOTAL SIGNATURE TYPES
WATER BORNE
AIR BORNE
pg 6 (C) up 3
pg 14 (C) down 2


3A (D)
A/B MACHINERY SIGNATURES
VISUAL/PARTICULARS
NOISE
HEAT
RADIATION
from pg 14 (C) down 2
pg 3 (E)
pg 15 (E) down 2
pg 3 (E) down 1
3A (D) down 1
A/B ELECTRONIC SIGNATURES
E C M
RADAR
RADIO/DATA LINK
from pg 14 (C) down 2
pg 17 (E) down 5
pg 17 (E) down 4
pg 15 (E) down 3


3A (E)
from pg 4 (D) up 1
from pg 2 (D)
A/B MACHINERY
NOISE SIGNATURES
MAIN PLANT
AUX.
3A (F)
A/B MAIN MACH. PLANT
HEAT SIGNATURES
PLANT TYPE
PLANT POWER
SURPRESSION LEVEL
POWER LEVEL
to 3A (F)
3A (E) down 1
from pg 2 (D)
A/B MACHINERY
HEAT SIGNATURES
MAIN PLANT
AUX. PLANT
to (F) down 1
3A (F) down 1
A/B AUX. MACH. PLANT
HEAT SIGNATURES
PLANT TYPE
PLANT POWER
SURPRESSION LEVEL
POWER LEVEL


from pg 6 (C) up 3
3A (D) up 2
HULL SIGNATURES (WB)
NOISE
WAKE
MAGNETIC
pg 10 (E) up 8
pg 9 (E) up 6
from pg 6 (C) up 3
3A (D) up 1
W.B. DECOY
SIGNATURE FUNCTIONS

from pg 15 (E) down 2

3A (F) up 2

A/B MAIN MACH. PLANT
RADIATION SIGNATURE

from pg 6 (D) up 4

3A (E) up 1

A/B MACHINERY
VISUAL SIGNATURE LEVELS

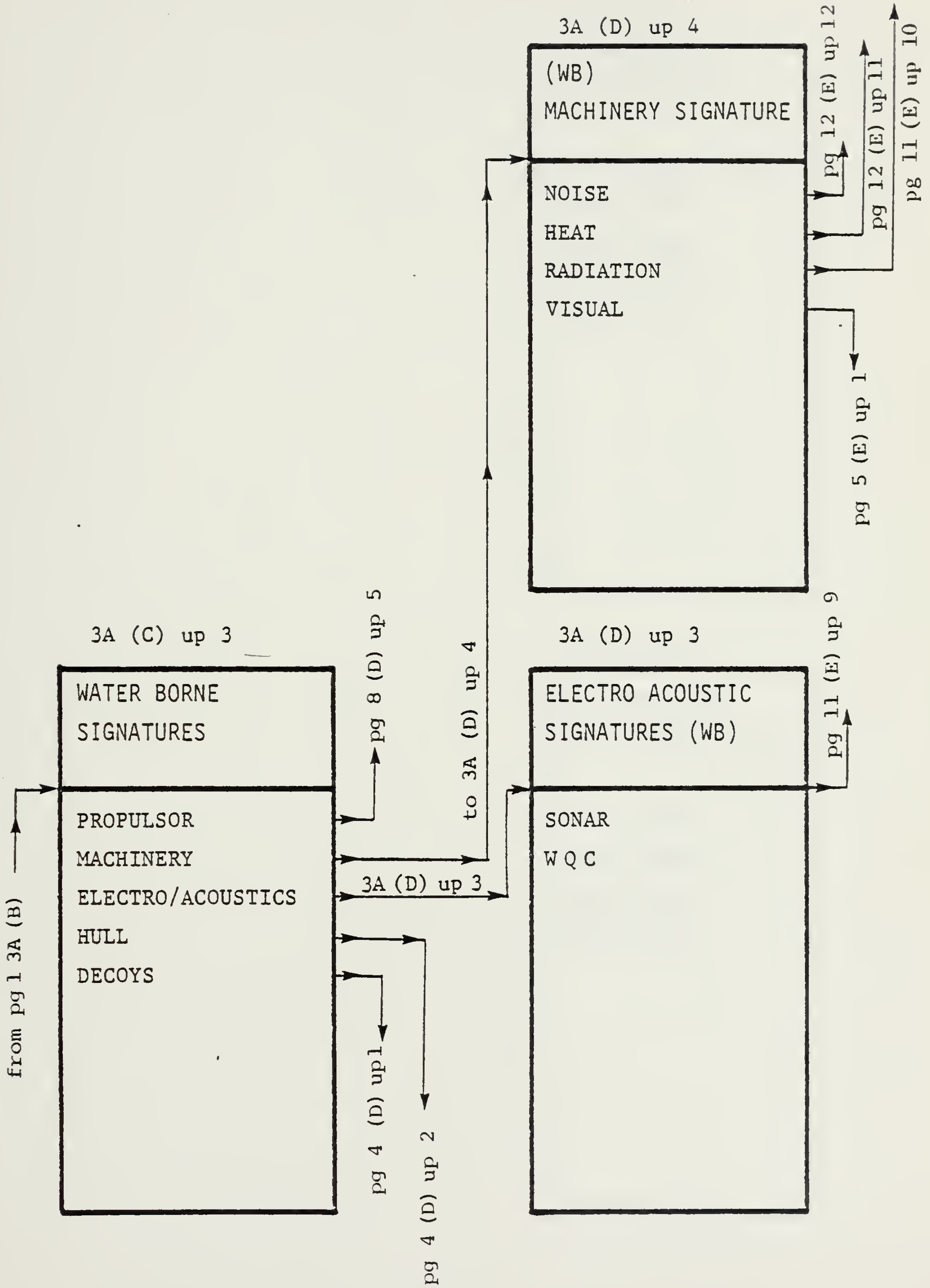
MAIN PLANT
AUX. PLANT

from pg 15 (E) down 2

3A (F) up 1

A/B AUX. MACH. PLANT
RADIATION SIGNATURE

PLANT POWER
SHIELDING
POWER LEVEL


3A (D) up 4
(WB)
MACHINERY SIGNATURE
NOISE
HEAT
RADIATION
VISUAL
pg 12 (E) up 12
pg 12 (E) up 11
pg 11 (E) up 10
pg 5 (E) up 1
3A (C) up 3
WATER BORNE
SIGNATURES
PROPULSOR
MACHINERY
ELECTRO/ACOUSTICS
HULL
DECOYS
from pg 1 3A (B)
pg 8 (D) up 5
to 3A (D) up 4
3A (D) up 3
pg 4 (D) up1
pg 4 (D) up 2
3A (D) up 3
ELECTRO ACOUSTIC
SIGNATURES (WB)
SONAR
W Q C
pg 11 (E) up 9

3A (F) up 4

MAIN MACHINERY
PLANT VISUAL (A/B)

from pg 5 (E) up 1

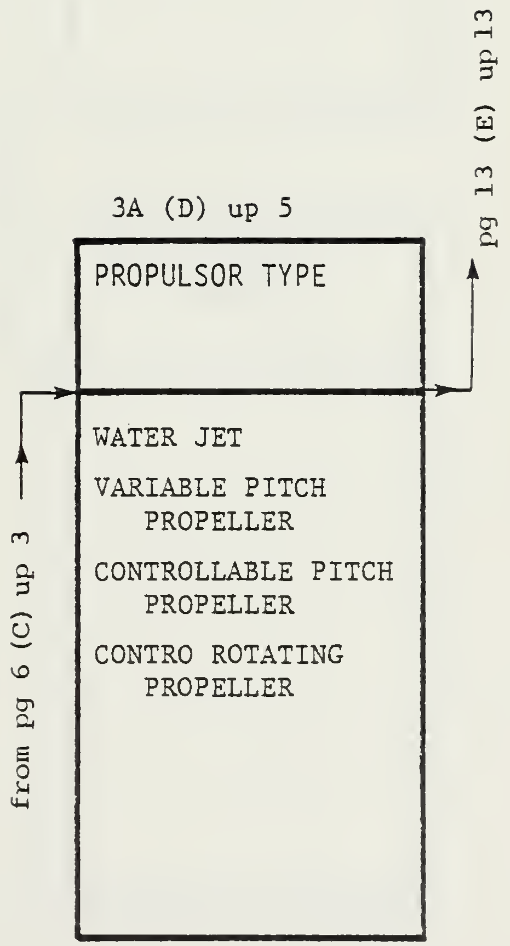
PLANT TYPE
PLANT POWER
FILTER LEVEL
POWER LEVEL

3A (F) up 3

AUX. MACHINERY
PLANT VISUAL (A/B)

from pg 5 (E) up 1

PLANT TYPE
PLANT POWER
FILTER TYPE
POWER LEVEL


3A (D) up 5
PROPULSOR TYPE
WATER JET
VARIABLE PITCH PROPELLER
CONTROLLABLE PITCH PROPELLER
CONTRO ROTATING PROPELLER
from pg 6 (C) up 3
pg 13 (E) up 13

3A (E) up 6

W/B HULL MAGNETIC
SIGNATURE FUNCTIONS

LENGTH
BEAM
DRAFT
MATERIAL

pg 4 (D) up 2

pg 12 (E) up 11

3A (F) up 6

AUX. MACHINERY
PLANT HEAT (W/B)

PLANT TYPE
PLANT POWER
PRE COOLING LEVEL
POWER LEVEL

pg 11 (E) up 10

3A (F) up 5

W/D RADIATION
SIGNATURE

3A (E) up 8

W/B HULL NOISE SIGNATURES

from pg 4 (D) up 2

STRUTS

SEA CHESTS

FORM

3A (F) up 8

from pg 12 (E) up 12

PRAIRIE NOISE (W/B)

BUBBLE

GENERATION EQUIPMENT

3A (F) up 7

from pg 12 (E) up 11

MAIN MACHINERY PLANT HEAT (W/B)

PLANT TYPE

PLANT POWER

PRE COOLING LEVEL

POWER LEVEL

3A (E) up 10

W/B MACHINERY RADIATION SIGNATURE

from pg 6 (D) up 4

pg 9 (F) up 5

3A (F) up 10

from pg 12 (E) up 12

AUX. MACHINERY PLANT NOISE (W/B)

PLANT TYPE

PLANT POWER

ISOLATION TECHNIQUE

POWER LEVEL

3A (E) up 9

W/E ELECTRO/ ACOUSTICAL SIGNATURE FUNCTIONS

from pg 6 (D) up 3

FREQUENCY

DUTY CYCLE

POWER OUT

DEPTH

TYPE?

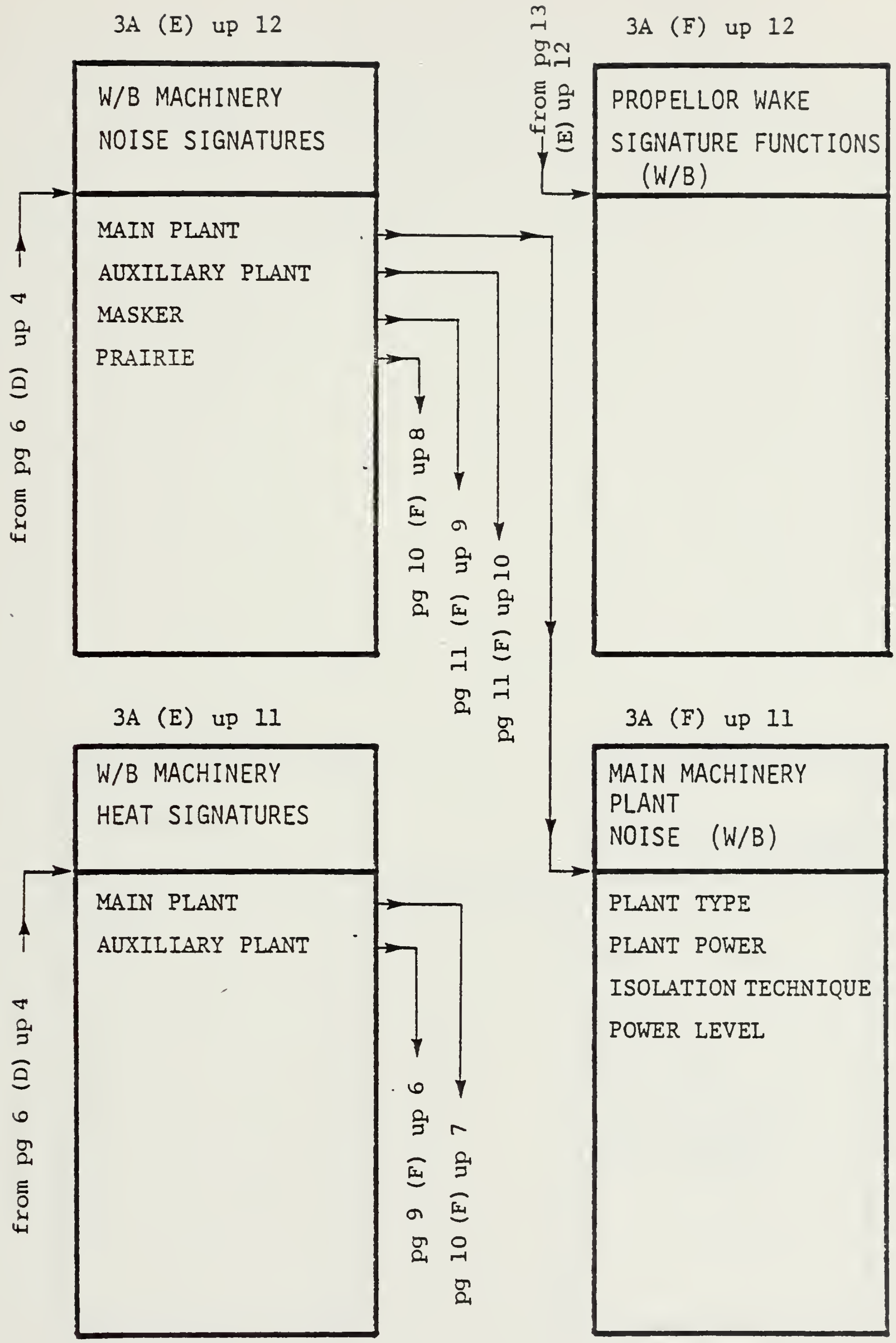
3A (F) up 9

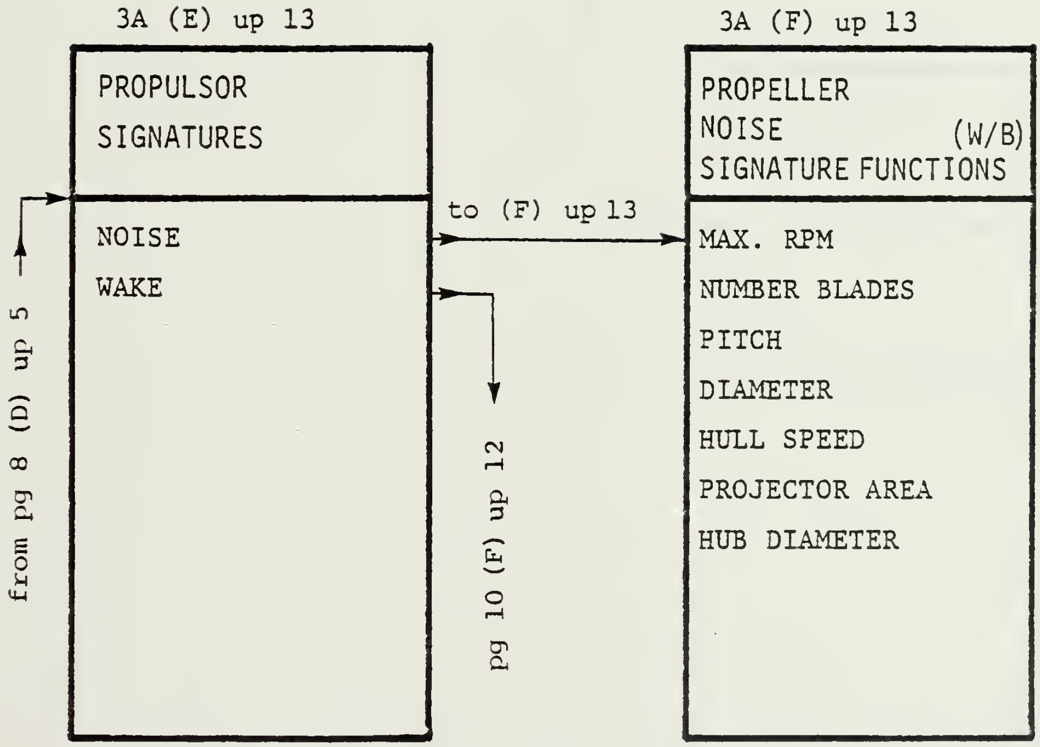
from pg 12 (E) up 12

MASKER NOISE (W/B)

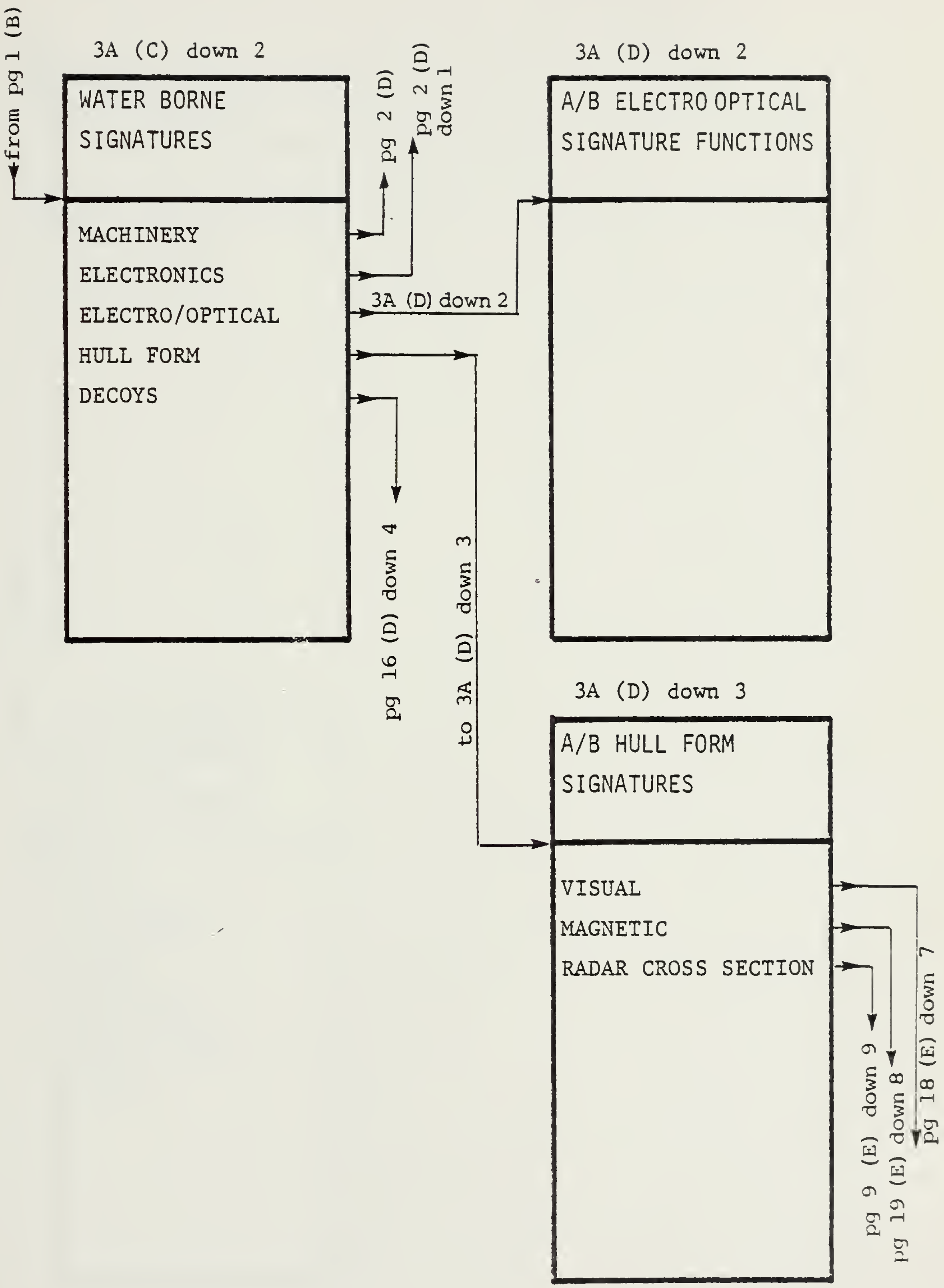
BUBBLE

GENERATION EQUIPMENT


3A (E) up 12
W/B MACHINERY
NOISE SIGNATURES
MAIN PLANT
AUXILIARY PLANT
MASKER
PRAIRIE
from pg 6 (D) up 4
pg 10 (F) up 8
pg 11 (F) up 9
pg 11 (F) up 10
3A (F) up 12
from pg 13 (E) up 12
PROPELLOR WAKE
SIGNATURE FUNCTIONS
(W/B)
3A (E) up 11
W/B MACHINERY
HEAT SIGNATURES
MAIN PLANT
AUXILIARY PLANT
from pg 6 (D) up 4
pg 9 (F) up 6
pg 10 (F) up 7
3A (F) up 11
MAIN MACHINERY
PLANT
NOISE (W/B)
PLANT TYPE
PLANT POWER
ISOLATION TECHNIQUE
POWER LEVEL



3A (E) up 13
PROPULSOR
SIGNATURES
NOISE
WAKE
from pg 8 (D) up 5
to (F) up 13
pg 10 (F) up 12
3A (F) up 13
PROPELLER
NOISE (W/B)
SIGNATURE FUNCTIONS
MAX. RPM
NUMBER BLADES
PITCH
DIAMETER
HULL SPEED
PROJECTOR AREA
HUB DIAMETER


from pg 1 (B)
3A (C) down 2
WATER BORNE SIGNATURES
MACHINERY
ELECTRONICS
ELECTRO/OPTICAL
HULL FORM
DECOYS
pg 2 (D)
pg 2 (D) down 1
3A (D) down 2
pg 16 (D) down 4
to 3A (D) down 3
3A (D) down 2
A/B ELECTRO OPTICAL SIGNATURE FUNCTIONS
3A (D) down 3
A/B HULL FORM SIGNATURES
VISUAL
MAGNETIC
RADAR CROSS SECTION
pg 9 (E) down 9
pg 19 (E) down 8
pg 18 (E) down 7

from pg 2 (D) down 1

3A (E) down 2

A/D MACHINERY
RADIATION SIGNATURE

MAIN PLANT → pg 5 (F) up 2

AUX. PLANT → pg 5 (F) up 1

from pg 2 (D) down 1

3A (E) down 3

A/B ELECTRONIC
ECM SIGNATURE

TYPE

FREQUENCY

POWER

BANDWIDTH

PULSE WIDTH

HEIGHT

3A (D) down 4

from pg 14
(C) down 2

A/B DECOY SIGNATURES

HEAT/IR

ELECTRO MAGNETIC

CHAFF

3A (E) down 4

from pg 2 (D) down 1

A/B RADAR SIGNATURE

TYPE
POWER LEVEL
FREQUENCY
PULSE WIDTH
HEIGHT

3A (E) down 5

from pg 2 (D) down 1

A/B RADIO SIGNATURE

TYPE
FREQUENCY
POWER
HEIGHT

from pg 14 (D) down 2

3A (E) down 6

A/B ELECTRO OPTICAL SIGNATURE

from pg 14 (D) down 3

3A (E) down 7

A/B VISUAL SIGNATURE

EMISSIVITY/REFLECTIVITY

LENGTH

BEAM

HEIGHT

from pg 14 (D) down 3

3A (E) down 8

A/B HULL FORM
SIGNATURE MAGNETIC

LENGTH

BEAM

HEIGHT

MATERIAL

from pg 14 (D) down 3

3A (E) down 9

A/B HULL FORM
SIGNATURE (RADAR C/S)

MATERIAL

OBLIQUENESS/
SMOOTHNESS

LENGTH

BEAM

HEIGHT

from pg 16 (D) down 4

3A (E) down 10

A/B DECOY SIGNATURES
HEAT

TYPE
RANGE
FIRING RATE

from pg 16 (D) down 4

3A (E) down 11

A/B DECOY SIGNATURES
ELECTRO MAGNETIC

TYPE
FREQUENCY
POWER
RANGE
FIRING RATE

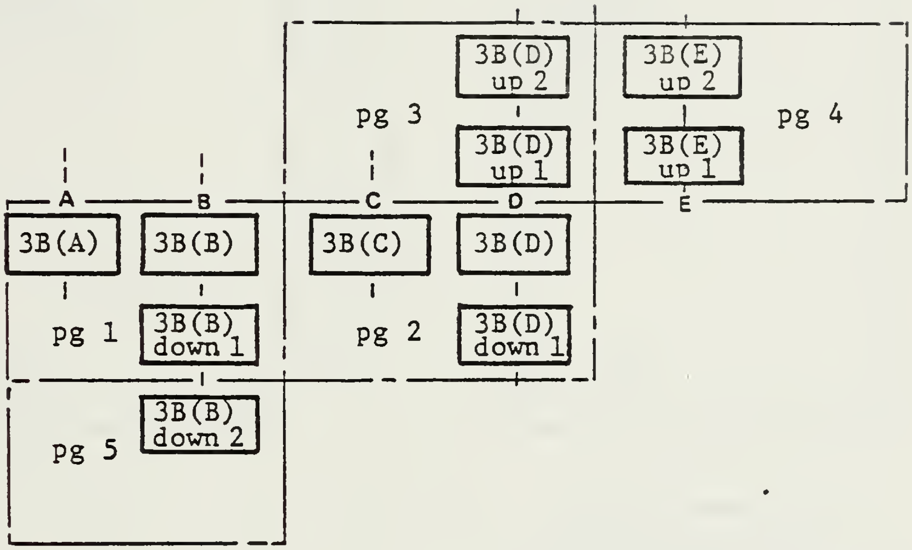
from pg 16
(D) down 4

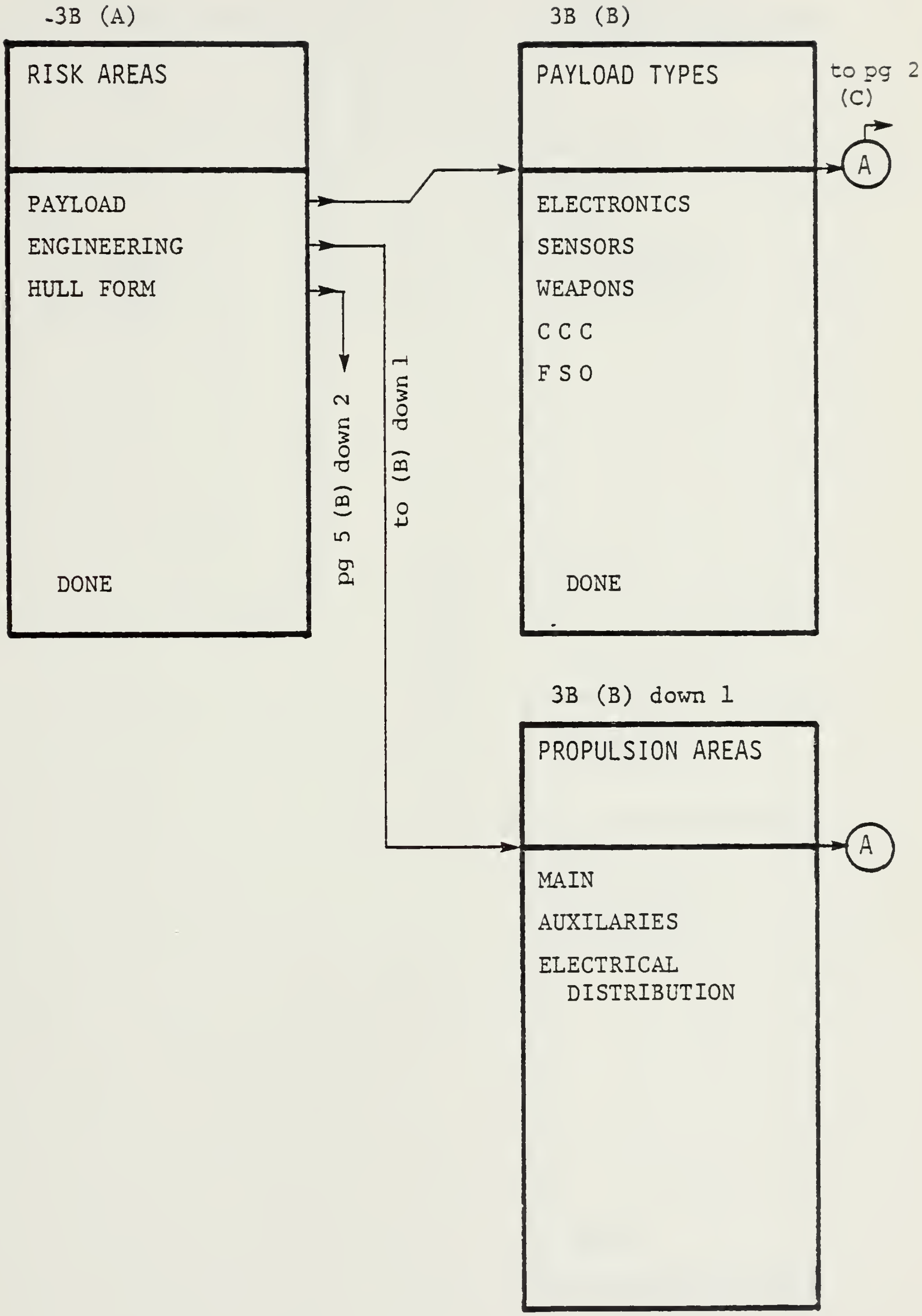
3A (E) down 12

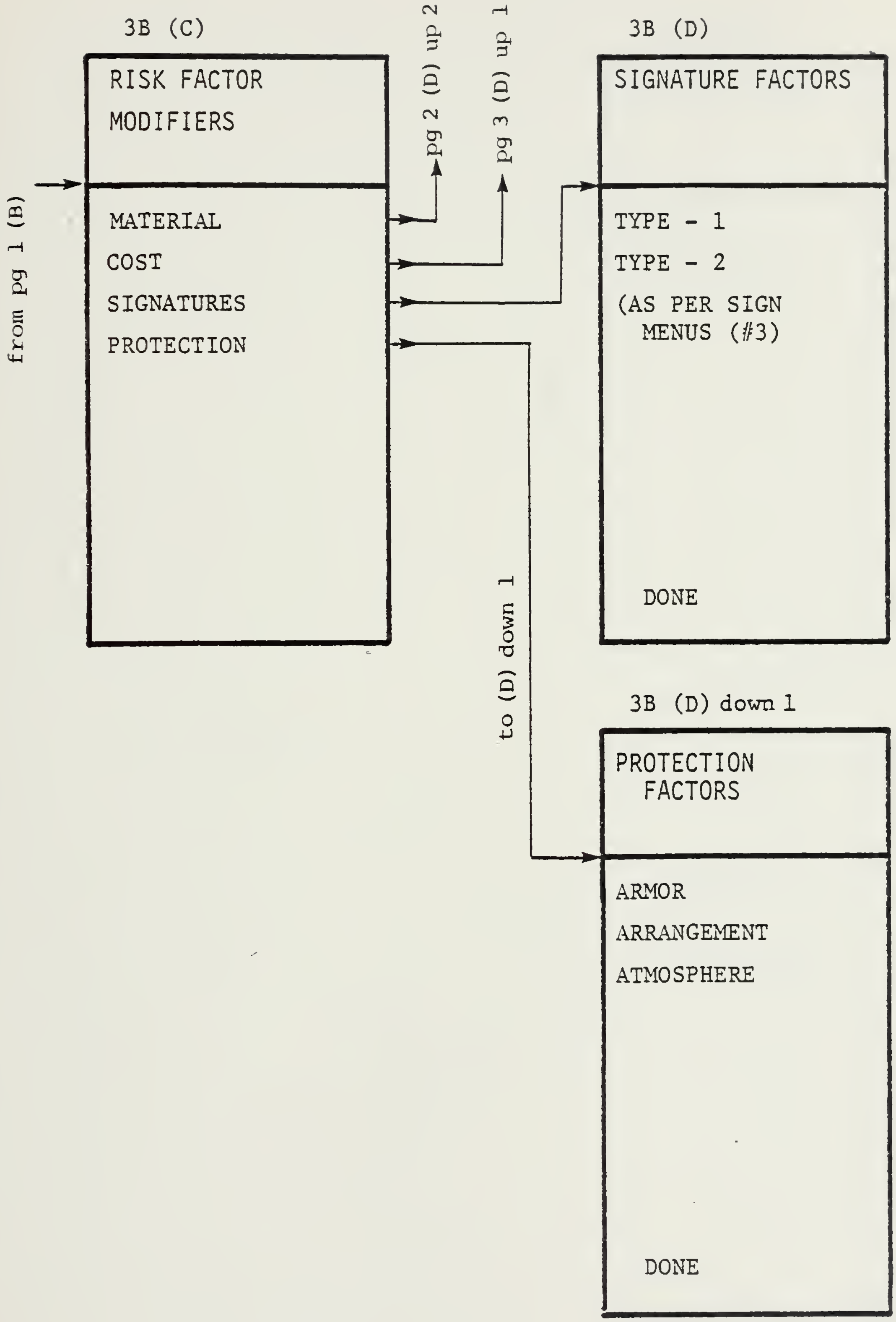
A/B DECOY SIGNATURES CHAFF
TYPE FREQUENCY RANGE FIRING RATE SIZE

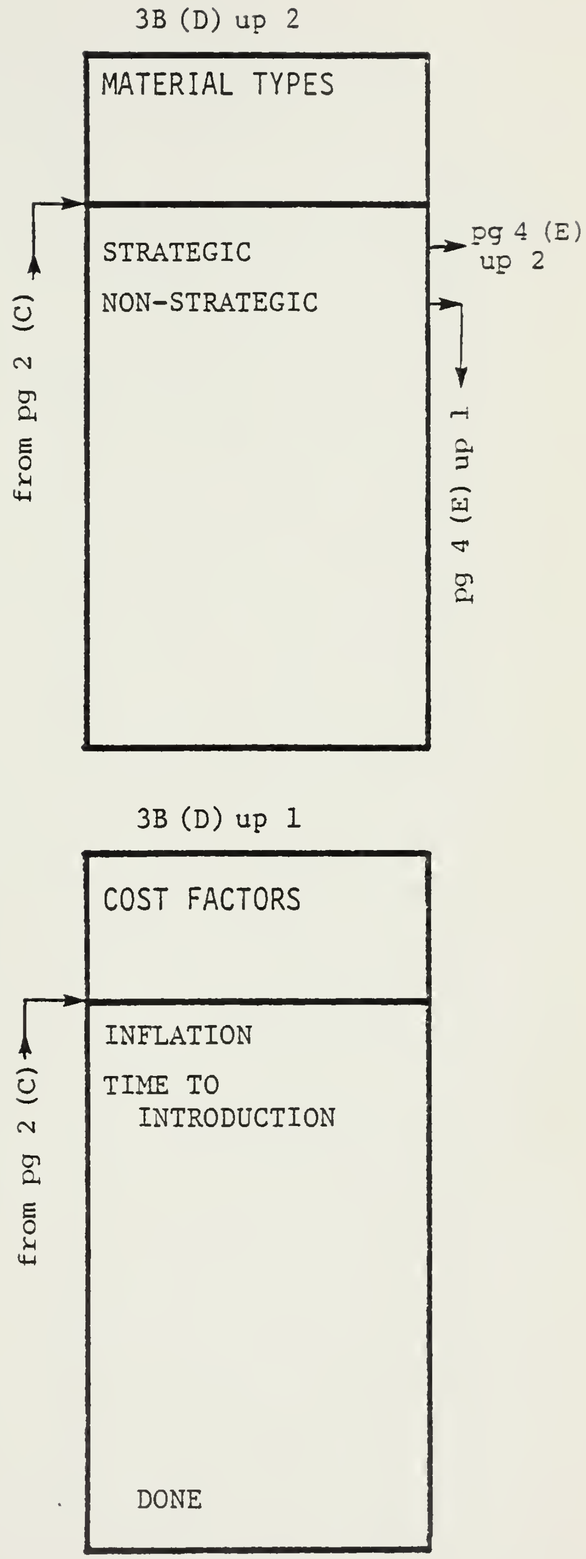
RISK FACTOR MENUS
(INPUT)
SECTION 3B

RISK FACTOR MENUS
(Input)
Section 3B




3B (A)
RISK AREAS
PAYLOAD
ENGINEERING
HULL FORM
DONE
pg 5 (B) down 2
to (B) down 1
3B (B)
PAYLOAD TYPES
to pg 2
(C)
A
ELECTRONICS
SENSORS
WEAPONS
C C C
F S O
DONE
3B (B) down 1
PROPULSION AREAS
A
MAIN
AUXILARIES
ELECTRICAL
DISTRIBUTION


3B (C)
RISK FACTOR
MODIFIERS
MATERIAL
COST
SIGNATURES
PROTECTION
from pg 1 (B)
pg 2 (D) up 2
pg 3 (D) up 1
3B (D)
SIGNATURE FACTORS
TYPE - 1
TYPE - 2
(AS PER SIGN
MENUS (#3)
DONE
to (D) down 1
3B (D) down 1
PROTECTION
FACTORS
ARMOR
ARRANGEMENT
ATMOSPHERE
DONE


3B (D) up 2
MATERIAL TYPES
STRATEGIC
NON-STRATEGIC
from pg 2 (C)
pg 4 (E) up 2
pg 4 (E) up 1
3B (D) up 1
COST FACTORS
INFLATION
TIME TO INTRODUCTION
from pg 2 (C)
DONE

3B (E) up 2

from pg 3 (D) up 2

STRATEGIC MATERIALS

MATERIAL 1
MATERIAL 2
MATERIAL 3
ETC.

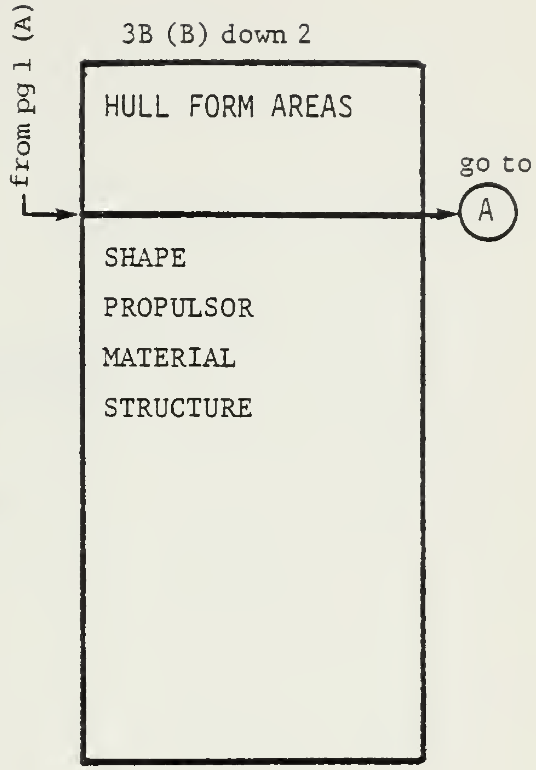
DONE

from pg 3 (D) up 2

3B (E) up 1

NON-STRATEGIC MATERIALS

MATERIAL 1
MATERIAL 2
MATERIAL 3
ETC.

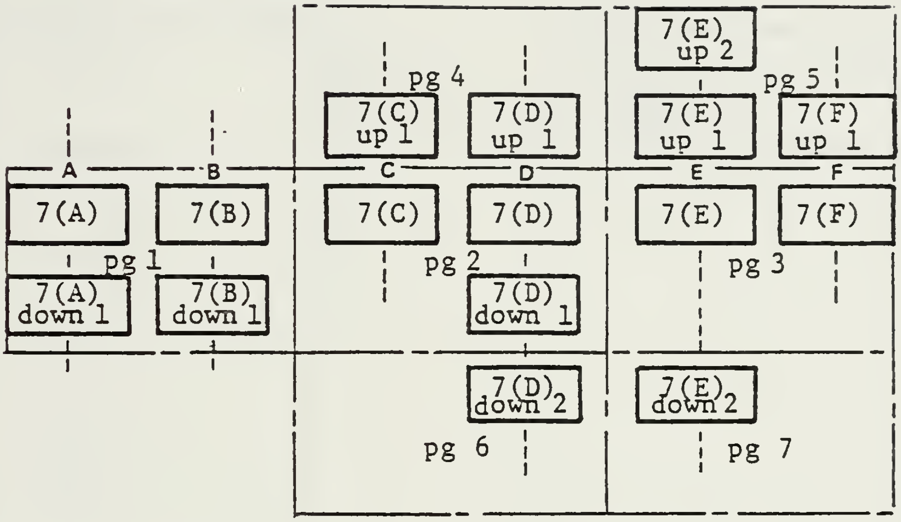

3B (B) down 2
from pg 1 (A)
HULL FORM AREAS
go to
A
SHAPE
PROPULSOR
MATERIAL
STRUCTURE

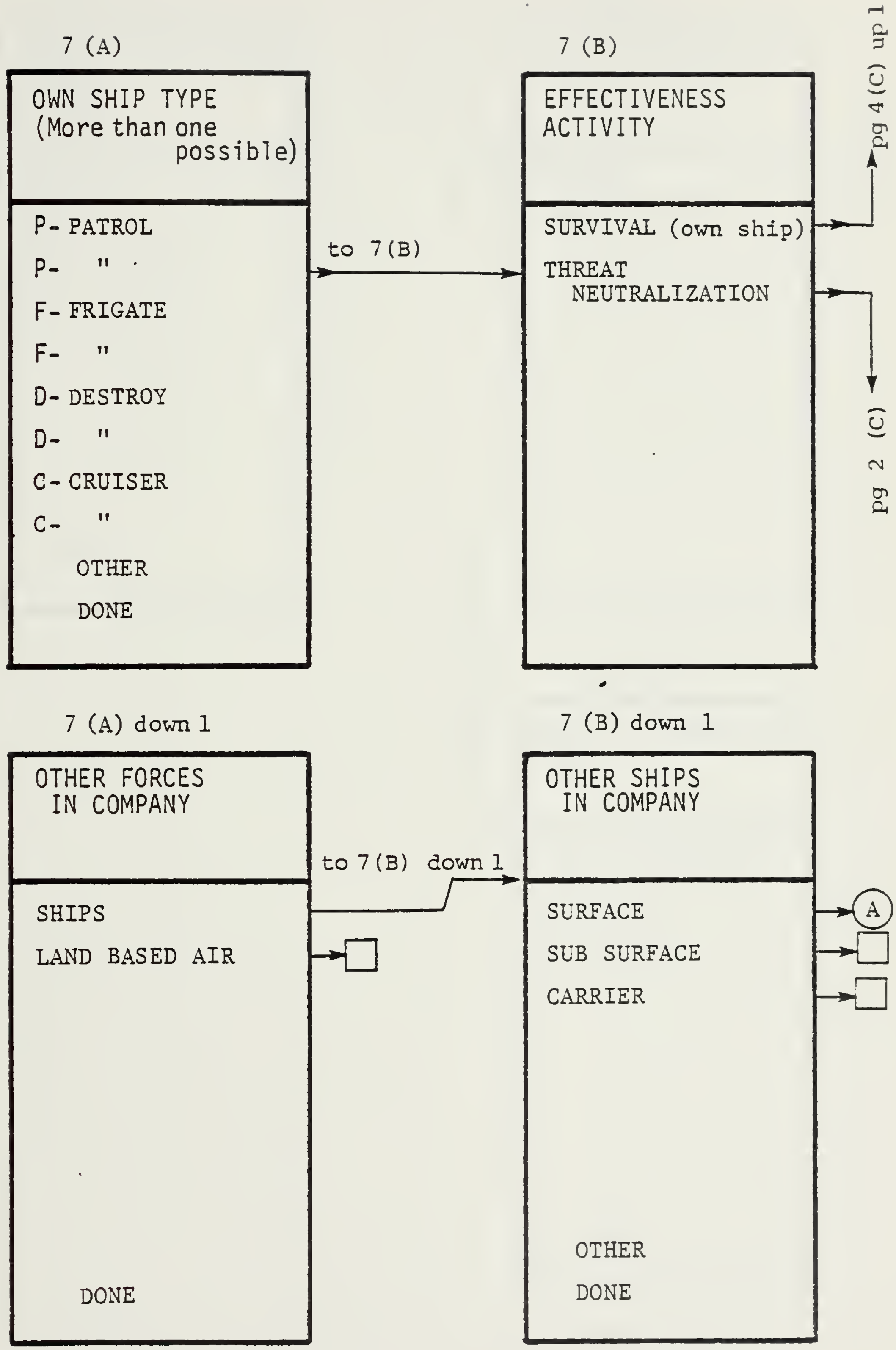
COMBAT EFFECTIVENESS
"MENUS"

(OUTPUT ONLY)

SECTION 7

COMBAT EFFECTIVENESS
"MENUS"
(OUTPUT ONLY)
SECTION 7





NOTE: ☆ ⇒ DEFAULTS TO DATE BASE (END OF LOGIC STRING)

□ ⇒ MENUS / LOGIC NOT DEVELOPED TO DATE

(A) ⇒ GOES TO "SHIP TYPE"

7 (C)

from pg 1 7(B)

THREATS NEUTRALIZED (TYPE)

SURFACE
LAND
SUB SURFACE
AIR

DONE

pg 6 (D) down 2

7 (D)

from pg 4(C) up 1

C.C.C. CAPABILITY TYPE

"FLAG"
"NON-FLAG"☆

pg 3 7(E)

7 (D) down 1

from pg 4(C) up 1

MOBILITY CAPABILITY TYPE

SPEED (PERCENT)☆
STABILITY
ENDURANCE

DONE

7 (E)

from pg 2 7(D)

FLAG C.C.C.
CAPABILITIES

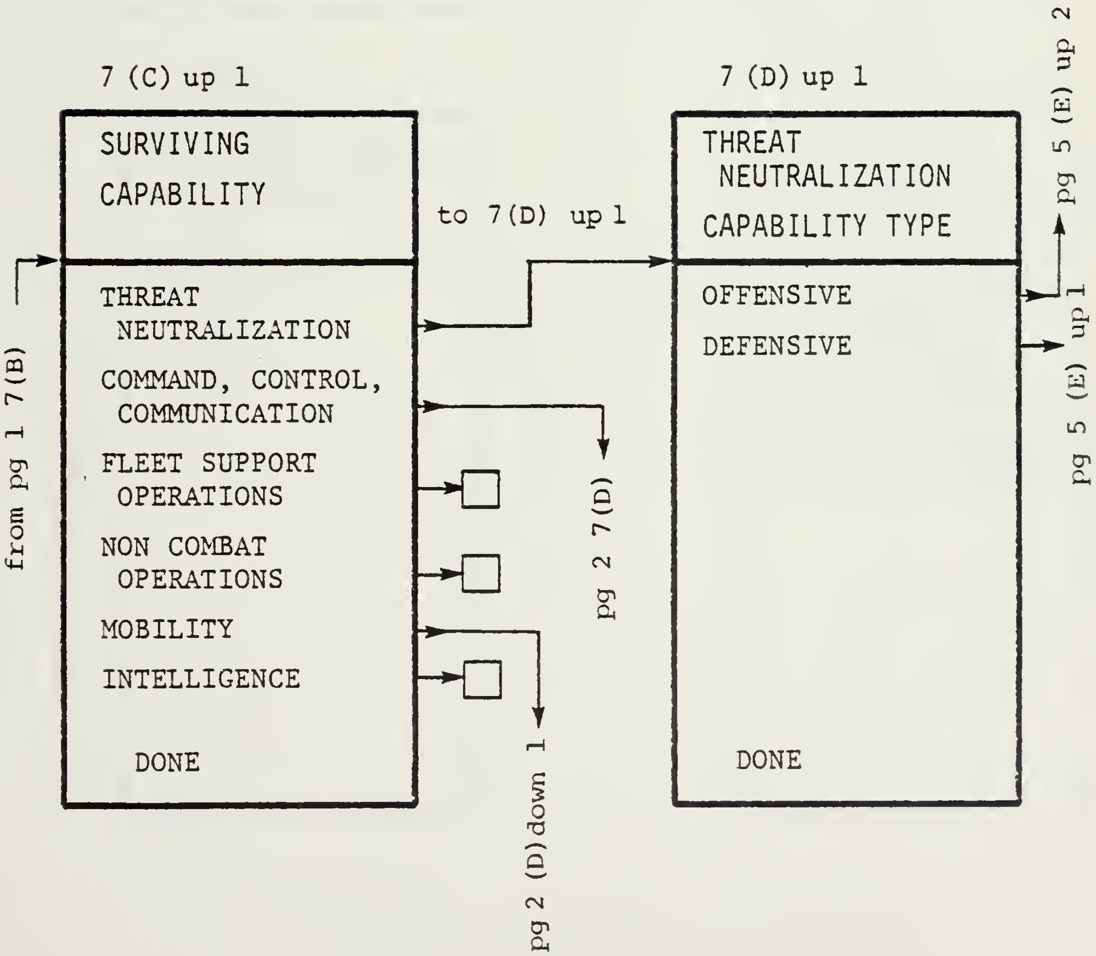
[APPROPRIATE
C.C.C. FUNCTION
MENU STARTS
(SECTION" COMMAND
CONTROL,
COMMUNICATION)
WITH PERCENT
REMAINING NOTATION
AVAILABLE]

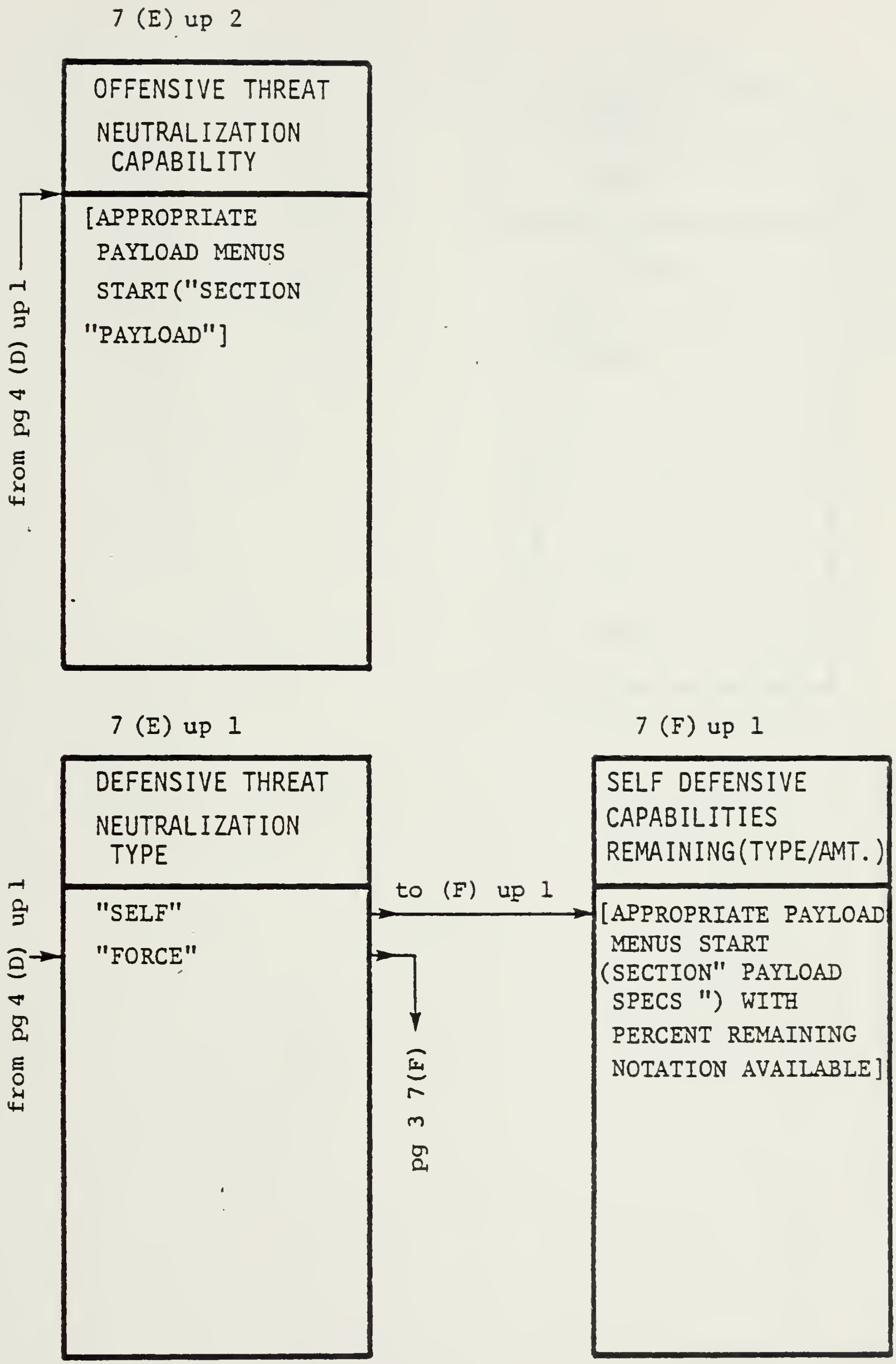
7 (F)

from pg 5 (E) up 1

FORCE DEFENSIVE
CAPABILITIES
REMAINING TYPE AMT.

[APPROPRIATE
PAYLOAD
MENUS START
(SECTION" PAYLOAD
SPECS.")
WITH PERCENT
REMAINING NOTATION
AVAILABLE]


7 (C) up 1
SURVIVING CAPABILITY
THREAT NEUTRALIZATION
COMMAND, CONTROL, COMMUNICATION
FLEET SUPPORT OPERATIONS
NON COMBAT OPERATIONS
MOBILITY
INTELLIGENCE
DONE
from pg 1 7(B)
to 7(D) up 1
pg 2 7(D)
pg 2 (D) down 1
7 (D) up 1
THREAT NEUTRALIZATION CAPABILITY TYPE
OFFENSIVE
DEFENSIVE
DONE
pg 5 (E) up 2
pg 5 (E) up 1



7 (E) up 2
OFFENSIVE THREAT NEUTRALIZATION CAPABILITY
[APPROPRIATE PAYLOAD MENUS START("SECTION "PAYLOAD"]
from pg 4 (D) up 1
7 (E) up 1
DEFENSIVE THREAT NEUTRALIZATION TYPE
"SELF"
"FORCE"
from pg 4 (D) up 1
to (F) up 1
pg 3 7(F)
7 (F) up 1
SELF DEFENSIVE CAPABILITIES REMAINING(TYPE/AMT.)
[APPROPRIATE PAYLOAD MENUS START (SECTION" PAYLOAD SPECS ") WITH PERCENT REMAINING NOTATION AVAILABLE]

7 (D) down 2

from pg 2 (C)

THREAT
NEUTRALIZATION
METHOD

TURN BACK

KILL

DAMAGE

DONE

to pg 7 (E) down 2

7(E) down 2

from pg 6 (D) down 2

THREATS DAMAGED
TYPE/AMOUNT/AREA

[APPROPRIATE "THREAT TYPE" (FROM SECTION" IA THREATS/ENVIRON-MENT)"

MENU STARTS WITH

"PERCENT" REMAINING"

NOTATION AVAILABLE]

DONE

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Thesis
D7014 Dowd
c.1

An investigation into the use of combat effectiveness as a method of selection of Naval vessel characteristics.